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A MANUAL OF
RIGGING FOR AIRCRAFT

This handbook, which deals briefly with the theory and practice of the rigging of aircraft, is issued for the information and guidance of all concerned.

By Command of the Air Council,

C. Ll. Bullock

AIR MINISTRY
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NOTE.

Nothing in this manual is intended to overrule official instructions issued to cover any specific point.

INTRODUCTION

1. The tendency in scientific and mechanical matters is generally towards specialisation. In the early years of practical aviation, say 1908 or 1909, it was not usual to specialise in any particular phase of aeronautical work. It was the rule then for one man to try out his own theories by designing, building, and flying his own aircraft. Many of the pioneers did wonderful work in these combined capacities, but the system obviously could not continue. To-day, the design, construction, and piloting of aircraft are sub-divided into a large number of highly specialised tasks, with a consequent increase in efficiency. Every good rigger should realise that from the first thoughts of the theorist to the actual flying of the aircraft there is a complete chain of workers, and that the links in the chain are all interdependent. If any one of the widely different kinds of work is performed badly, or if any mistake is made, all the good work of the rest cannot set matters right. The design of the aircraft must be right, mathematically, aerodynamically, and mechanically; the construction must be sound, both in workmanship and choice of materials; the aircraft must be rigged according to the designer's intentions, and, lastly, the pilot must be capable. If any of these links in the chain should be faulty, failure, and perhaps disaster, follows.

2. The function of the rigger should now be more or less clear. His duties are to make the best use of the work of designer and constructor, so that the pilot may fly an aeroplane that is rigged truly and safely and in accordance with the designer's ideas. The days when a rigger had, so to speak, to finish off the designer's work are now past. In the early days of the war it was not unusual for the efficiency of the rigger to make up for minor faults in design, and many a good pilot and rigger between them obtained a better performance from an aeroplane than the designer had thought possible. On the other hand, careless or ignorant rigging has sometimes caused the loss of just that excellence of performance that would have enabled a pilot to overcome an opponent.

3. To-day it is no longer the rigger's function to question or alter the designer's arrangements. He must simply make certain that the relations of the various surfaces are exactly

as the designer planned, and that the various adjustments are properly made and securely locked. This does not mean that the studies of a rigger need be curtailed in any way. On the contrary, a study of the aerodynamical and mechanical sides of aviation will help him to grasp the great importance of accuracy in his adjustments and repairs, and assist him to work with sympathy and intelligence.

4. The rigger takes over an aircraft either assembled, if delivered by air, or dismantled, if it arrives by road or other transport. There are, in addition, many occasions on which a rigger must assemble and true up an aircraft which has been dismantled for repair or other purposes. In any case, his duty is to check very carefully the disposition of the fuselage and planes, tail and undercarriage, and other parts, and to examine, as far as possible, all wires, cables, struts, sockets, etc. He must make quite sure that the geometry of the aircraft is correct, i.e., that the undercarriage is symmetrical, the planes are symmetrical to the fuselage, and so on. Also he must watch for frayed cables, faulty wires or fork ends, loose nuts and damaged or missing split pins. The great responsibility of the work is self-evident. The pilot is more or less at the mercy of all who have been concerned with the design, construction, and erection of his aircraft, and it is not likely that the rigger, who is generally in fairly close contact with the pilot, would fail to realise his own responsibilities.

5. So far as Service aircraft are concerned, the duties of the rigger, and the periods between overhauls and inspections, are dealt with in Air Ministry Weekly Order 25 of 1929, as amended by subsequent orders, and in the King's Regulations and Air Council Instructions, paras. 702 and 788.

CHAPTER I.

AERODYNAMIC PRINCIPLES.

6. Most good riggers have a knowledge of the aerodynamic laws that govern the flight of heavier-than-air craft. No attempt is made in this chapter to explain these laws, but brief explanations of the terms in common use are given as a guide. Those interested in the theory of flight are referred to Air Publication 129, Flying Training Manual, Part I, and other publications where the subject is more fully dealt with. For further explanations of the nomenclature and the definitions of the expressions used in connection with aeroplanes and aerodynamics which are not mentioned here, reference should be made to the "British Standard Glossary of Aeronautical Terms."

The Atmosphere.

7. It is general knowledge that the earth is surrounded by a layer of colourless and invisible gas known as air. It is usual, for particular purposes, to speak of this layer as being about 10 miles thick, but it would be impossible to draw a line where the air actually ends because the atmosphere presumably "shades off" very gradually into the space that exists between our earth and other bodies. The air is most dense near the ground, and becomes more and more rarified as the distance from the ground increases. The air has certain properties, the variation of which affect the flight of all types of aircraft, and of these properties the most important is perhaps that of "density."

Air density, pressure, and temperature.

8. Before any definite figures can be specified for the density of the air, some standard conditions of barometric pressure and temperature must be stated, because the air density is directly affected thereby. It is usual to take, as a standard, the pressure which corresponds to a mercury barometer reading of 760 mm., or 29·92 in., which is equivalent to 14·7 lb./sq. in. The standard temperature adopted varies somewhat, but is generally accepted as 60° Fahrenheit or 15° Centigrade at sea level, decreasing by 2° Centigrade (or its equivalent in degrees Fahrenheit) per thousand feet of elevation. The density of the air under these standard conditions of pressure and temperature is ·0766 lb./cub. ft., which, stated in a simpler way, means that 13 cub. ft. of air weigh nearly 1 lb.

9. The pressure of the air at sea level varies with atmospheric conditions, so that a pressure-measuring instrument, such as an aneroid or an altimeter, will not read zero height at ground level unless the barometer reading is 29·92 in. and the aerodrome is at sea level. The aneroid reading changes at sea level by approximately 90 ft. per 0·1 in. change in barometer reading. In order to obtain a true comparison, all full-scale tests must be made at the same air pressure, that is, the same altimeter reading, which is not necessarily at the same height from the ground. Given the same air pressure, the air density will change with every alteration of temperature ; therefore the air temperature must also be observed so that results can be converted to standard conditions.

10. Amongst the other properties of air is that of humidity, which can be defined as amount of water vapour present in the air. The effects of humidity on the flight of an aeroplane are negligible, and therefore no corrections are made for this condition.

Aerofoils.

11. An aerofoil is a structure analogous to the wing of a bird, designed to obtain reaction from the air approximately at right angles to the direction of its motion. This reaction is recorded in fig. 1 by a line AC, which leans a little backward from the normal to the direction of motion. This line represents the resultant force, which is usually resolved into

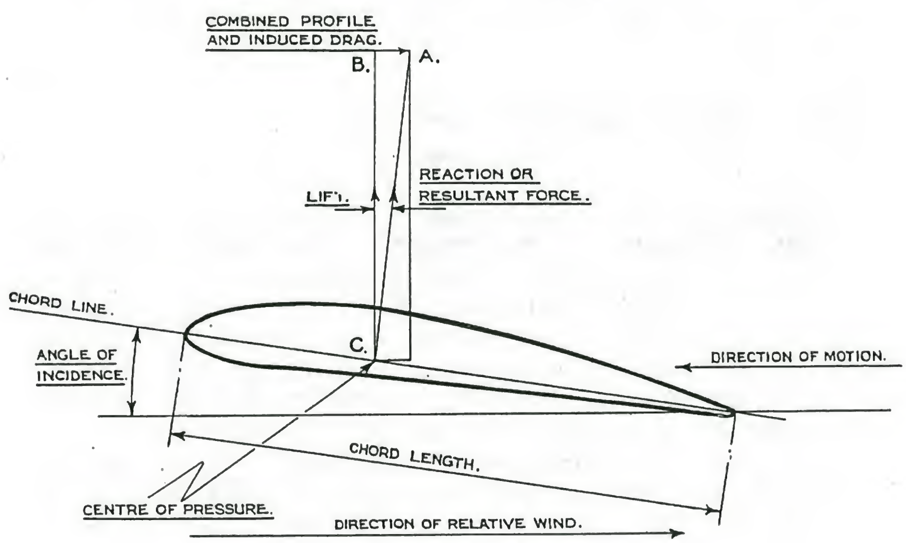

FIG. 1.—Diagram of forces of an aerofoil.

two forces known as lift and drag, represented by BC and BA respectively. The lift and drag of an aerofoil are the most important of its characteristics.

Lift.

12. The lift can be defined as that component of the resultant force which is perpendicular to the direction of the relative wind.

Drag.

13. The drag of an aerofoil may be defined as that component of the resultant force which is parallel to the direction of the relative wind.

Aerofoil section.

14. The aerofoil sections employed are sometimes symmetrical about a line drawn through the leading and trailing edges, but they are more often cambered. An aerofoil is cambered when its centre line is curved, and the camber is usually denoted as the maximum height of the aerofoil centre line above and at right angles to the chord line. For convenience, this height is usually expressed as a fraction of the chord. There are many types of aerofoil sections employed, all of which have slightly different characteristics. Thin wing sections of low camber have least drag, but thick and high camber sections usually give greater maximum lift coefficents. Another rather important characteristic of an aerofoil is its centre of pressure travel. This characteristic varies with each section employed, and is practically non-existent in symmetrical sections.

15. Two of the curves in fig. 2 show how the lift and drag of an aerofoil vary with the angle of incidence (i.e., the angle between the chord of the aerofoil and the direction of motion) when the speed at which the air passes over the wing is kept constant. The lift is seen to be roughly proportional to the incidence up to about 14°, at which angle it reaches a maximum and the aerofoil is said to stall. The drag has been constantly rising and rises very rapidly after the stall. The third curve shows the ratio of lift to drag. The most efficient aerofoil is clearly one that gives the highest value of this ratio. It is also clear that that an aerofoil is most efficient at the angle corresponding to maximum lift/drag, i.e., at 3° to 4° in this case.

Chord.

16. The chord of an aerofoil is the line passing through the centres of curvature of the leading and trailing edges, the length of the chord being the distance between these edges.

This will be more clearly understood if read in conjunction with the description of incidence given in para. 19.

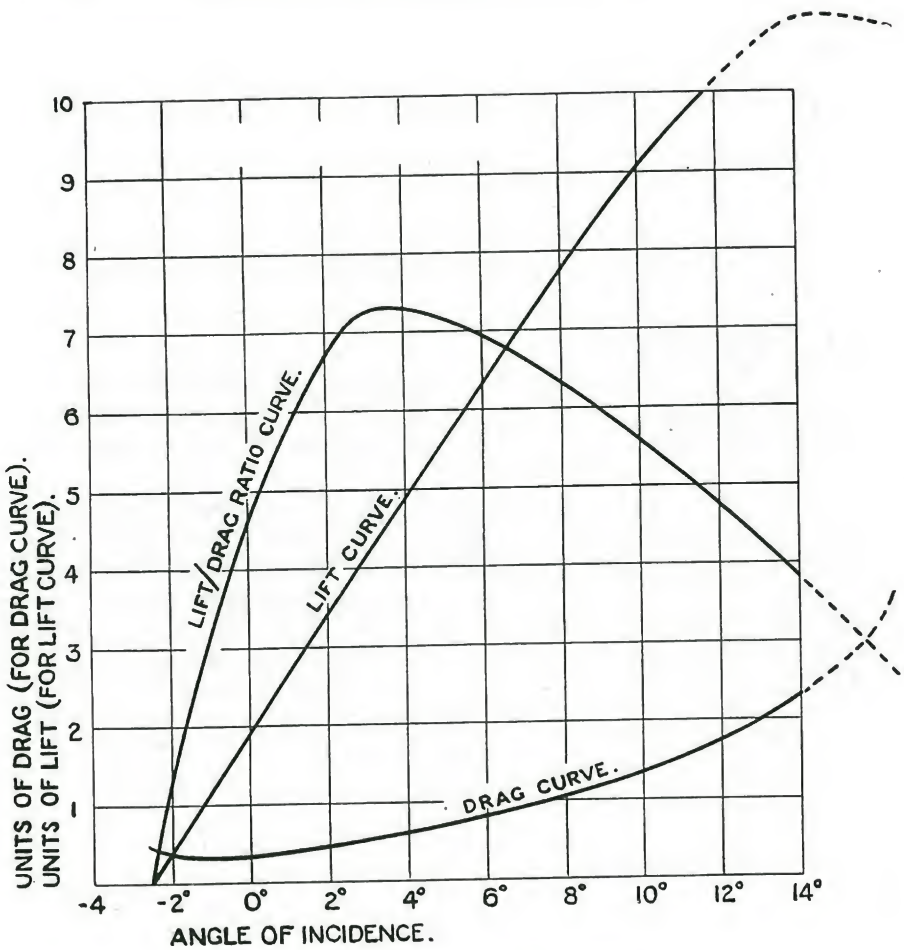

FIG. 2.—Lift and drag curve.

Centre of pressure.

17. The lift of an aerofoil is usually considered as being composed of an infinite number of small forces or pressures acting upwards at all points of the surface. A pressure distribution curve for a typical aerofoil is given in fig. 3. If all these small forces are combined and considered as the action of a single force, the point where the line of action of this force cuts the chord is known as the centre of pressure, as indicated in fig. 1. The position of the centre of pressure is usually given as a percentage of the chord from the leading edge. For all types of aerofoil, other than one with symmetrical section, the position of the centre of pressure varies

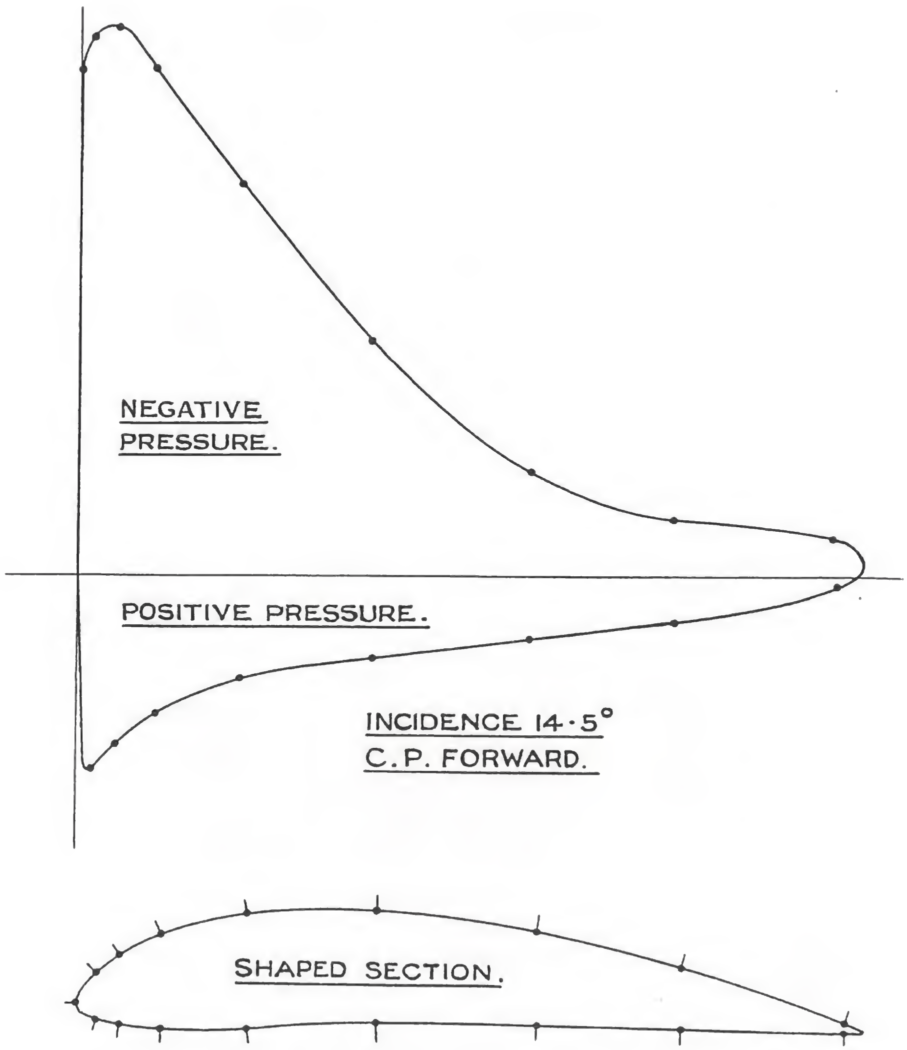

FIG. 3.—Pressure distribution curve.

with the incidence. When the aerofoil is at an angle of no lift, that is, at such an incidence that no resultant upward or downward force is being applied to the aerofoil, the centre of pressure is theoretically at an infinite distance behind the aerofoil, and as the angle is increased the centre of pressure travels forward. The normal centre of pressure travel varies with the different aerofoil sections used, but for a symmetrical section the position is constant over a large range of angular movement. This is advantageous from the aspect of the strength of the members involved, but the symmetrical type of section is not the most efficient as a lifting surface.

SUPPORTING SURFACES.

18. The supporting surfaces of an aeroplane are those which directly contribute to the sustaining of the aeroplane in the air, as considered apart from the control surfaces. Theoretically there is no reason why an aeroplane should not have as many main supporting surfaces as desired, but on the score of general efficiency and the cost of production and maintenance, modern aeroplanes seldom have more than two. The supporting surfaces of an aeroplane are usually termed the planes, and when determining the size and disposition of these parts the chief considerations, apart from the shape of the aerofoil in cross section, are the incidence, span, chord, dihedral, stagger, gap and sweepback.

Incidence, angle of.

19. Theoretically, the angle of incidence is the angle between the chord line, as defined in para. 16, and the direction of the relative wind. Practically, this angle cannot be measured by the rigger, so for rigging purposes an equivalent angle is used which is measured from the horizontal. When the underside of the plane is concave, so that when applied a straightedge will take up a definite attitude with relation to the true chord line, then the angle of incidence normally given to the rigger is the angle between the horizontal and the top surface of a straightedge held up against the underside of the plane at a rib when the aircraft is in rigging position. This angle is measured by a clinometer. When the underside of the plane is convex, then the angle of incidence cannot be defined by this method ; therefore it is usual to take as the angle of incidence the angle made by the top surface of a straightedge and the horizontal, when the straightedge is held up against the surface of the plane in such a position as to be parallel with the chord line. The distances from the top surface of the straightedge to the centres of curvature of the leading and trailing edges will then be equal. It is usual, however, for special incidence boards to be supplied for use with bi-convex sections, and detailed rigging instructions are generally available.

Span.

20. The span, as indicated in fig. 4, is the overall distance from wing tip to wing tip. The efficiency of the planes near the tip is considerably less than the efficiency over the centre portion of the plane. An aerofoil which has a long span in comparison with its chord will, area for area, be more efficient than an aerofoil which is comparatively short and wide.

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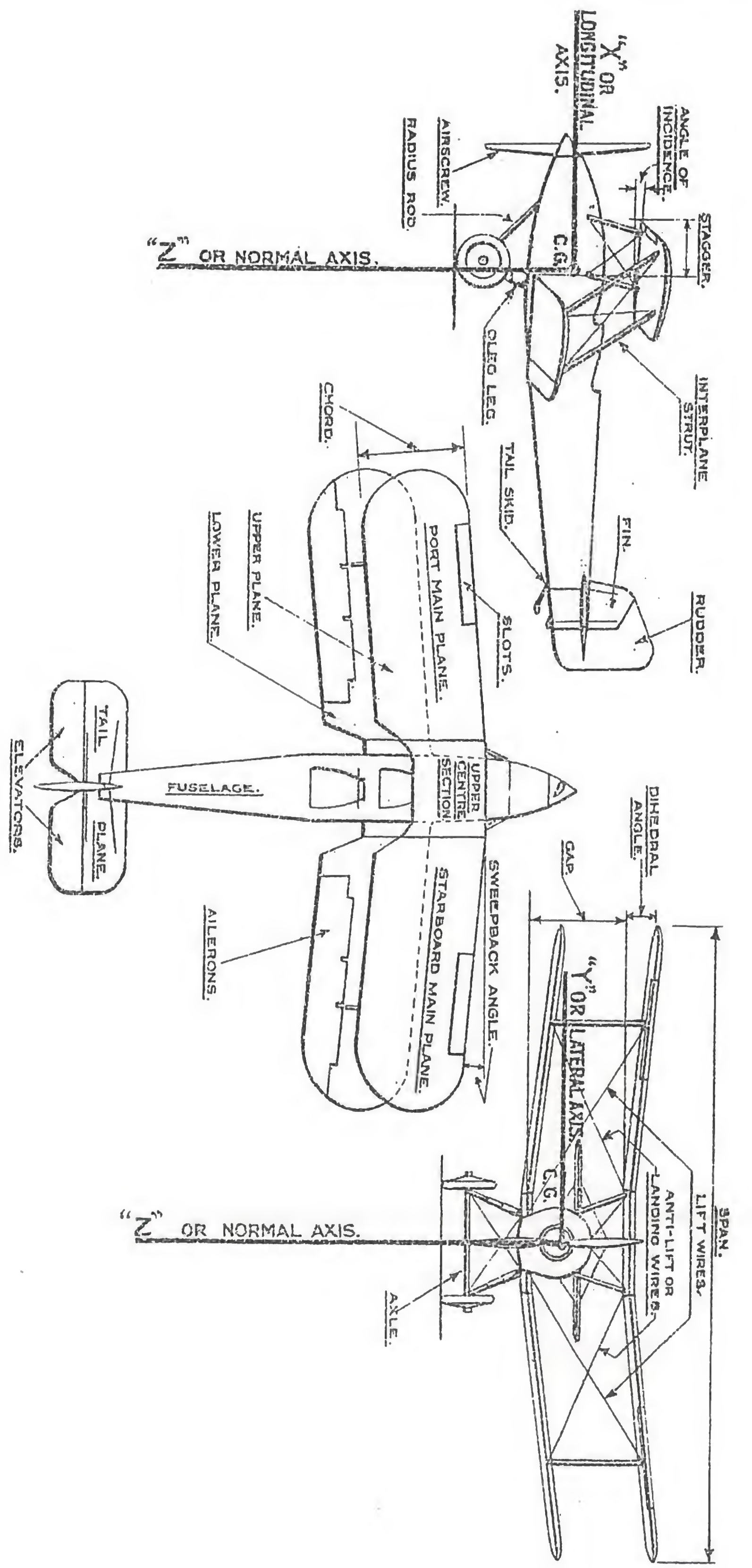

FIG. 4. AIRCRAFT TERMS.

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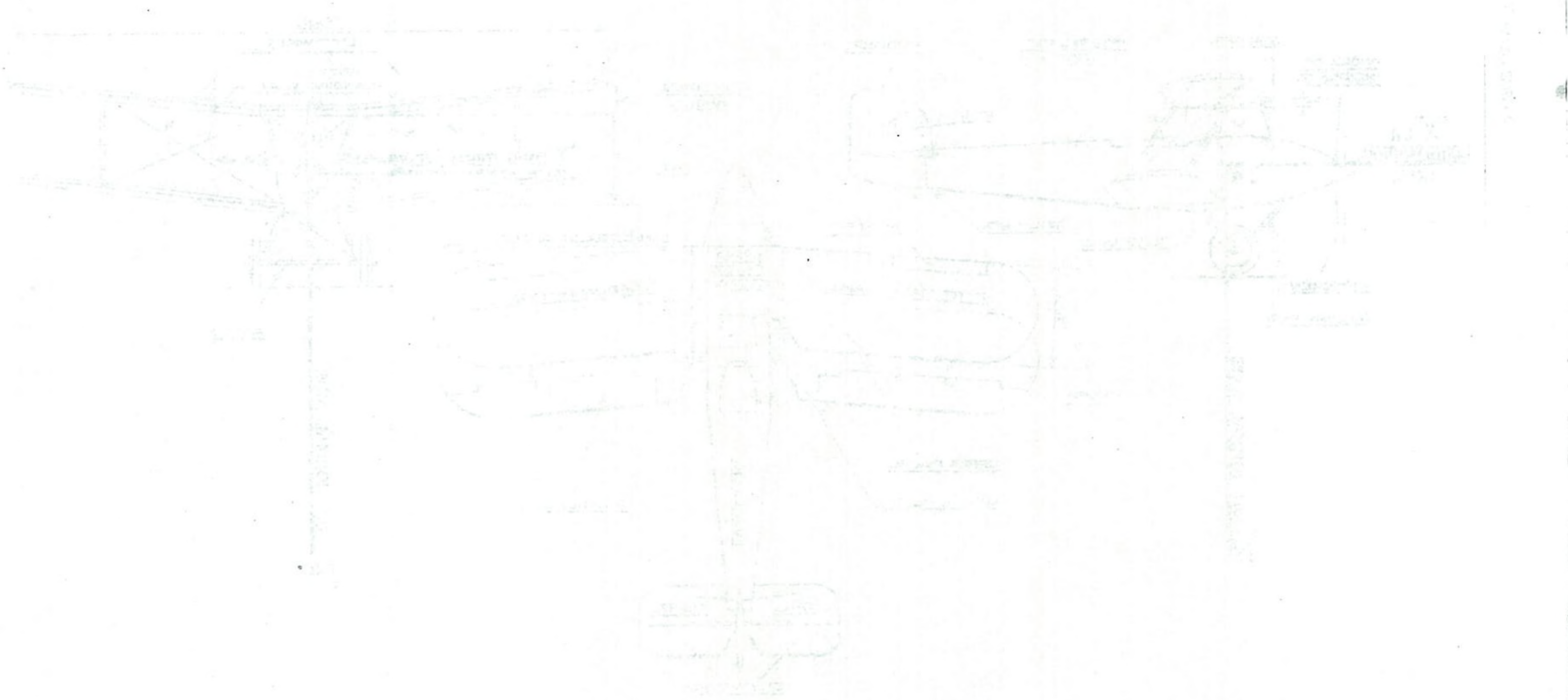

Aspect ratio.

21. The ratio of the span to the chord of a plane is called the aspect ratio, and, as explained above, planes which have high aspect ratio, that is, with a big span and a small chord, are more efficient than those with a low aspect ratio.

Gap.

22. There is another consideration which affects the efficiency of biplanes and that is the distance between one plane and the next immediately above or below it. This distance, shown in fig. 4, is termed the "gap" and is important from the point of view of the interference with the air flow over one plane caused by the plane above or below it. A small gap tends to reduce the efficiency of aerofoils. The top planes are always more efficient than the bottom planes, which brings about the common arrangement of large upper and smaller lower planes. The gap is usually measured directly from the leading edge of one plane to the leading edge of the other, and, owing to the sweepback effect due to dihedral may vary according to whether the measurement is taken at the centre section or the wing tip.

Dihedral.

23. In order to obtain additional stability in flight, many aeroplanes have their planes inclined upwards with relation to the transverse axis. The dihedral, in geometry, is the angle between any two planes, and a dihedral angle of an aeroplane is shown in fig. 4, and is the angle formed between the upwardly inclined plane and a horizontal line taken from any point. If inclined upward, the dihedral is positive; if downward, the dihedral is negative. As a negative dihedral would detract from the inherent stability of the aeroplane it is never employed.

Stagger.

24. In order, amongst other considerations, to reduce the interference owing to the close proximity of the planes to one another, one plane is often brought further forward with relation to another. In these circumstances the planes are said to be staggered, and the amount of stagger is measured by dropping a plumbline over the leading edge of the upper plane, when the aeroplane is in rigging position, and measuring from the plumbline to the leading edge of the lower plane. The stagger is almost invariably measured at the centre section. When the upper plane is in advance of the lower plane then the stagger is stated to be positive. Negative stagger occurs when the lower plane is in advance of the upper plane, and is a very rare occurrence in modern design. In addition to the various aerodynamic considerations involved, stagger is employed by the designer to obtain a larger field of view for the crew.

Sweepback.

25. In many aeroplanes the main planes in plan view are inclined backward as shown in fig. 4, thereby making an angle of less than 90° with the fore-and-aft centre line of the fuselage. The planes are swept back to give better longitudinal stability, and in spite of the fact that it introduces certain constructional difficulties, the practice is fairly common. It is not usually necessary for the rigger to check sweepback on the planes as this is usually fixed by the attachment fittings. A check for symmetry of the planes in plan view is all that is normally required.

CONTROLLING SURFACES.

26. In order to be of practical value, an aeroplane should be controllable under all conditions of flight which it is likely to encounter. There are quite a number of possible forms of control for aircraft, but no system has proved quite as simple and effective as that which is now practically universal. Generally speaking the flight of an aeroplane is controlled by means of subsidiary aerofoils so disposed about the aircraft that they provide control about the three principal axes. The control surfaces normally fitted are ailerons, elevators and rudders. Ailerons control the rolling movements which have the longitudinal axis as a pivot, the elevators affect movements having the transverse axis as a pivot, while the rudder controls yaw, or movements pivoted about the normal axis.

Ailerons.

27. Ailerons are aerofoils used for causing an aeroplane to roll about its longitudinal axis. The normal type of aileron is shown at A, fig. 5, and as will be seen, it forms a hinged continuation of the main aerofoil section near the wing tip, and often has some form of balancing surface. The action of ailerons is virtually to increase the angle of incidence of the wings on one side and decrease it on the other, thereby increasing or decreasing the lift. The rolling and yawing forces produced by the downward movement of an aileron are approximately equal to those produced by an equal upward movement of the aileron. Above stalling incidence the rolling forces remain about the same for equal movements, but the yawing, or drag force is greatly increased on the wing where the

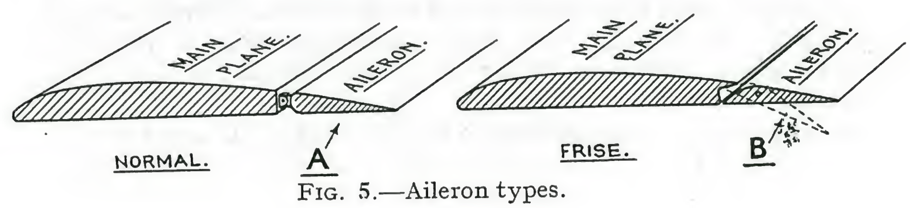

FIG. 5.—Aileron types.

aileron is down. For this reason, many ailerons are fitted with a mechanical differential action, so that, as the control column is moved right over, the elevated aileron continues its movement until the stop is reached, but the depressed aileron ceases its angular movement and in some cases even slightly reverses its motion at a point which gives the maximum rolling movement. A normal system of aileron control is shown in fig. 81.

28. There are some forms of aileron, such as the Frise shown at B, fig. 5, in which a similar action is obtained aerodynamically. With this type the ailerons on both sides move through equal angles and are effective at angles closer to the stalling angle than would be the case with a conventional type. In a normal arrangement the leading edge of the aileron is situated approximately level with the lower surface of the plane, whilst the hinge position is about a quarter of the chord of the aileron back from the leading edge. The exact aerodynamic considerations involved for the various types of differential aileron systems are a little obscure, but the aim of all systems is the same, i.e., to obtain the desired rolling moment as free as possible from yawing moment.

Elevators.

29. The elevators usually take the form of horizontal control surfaces, which form a continuation of the tail plane and are hinged to the rear spar. The action of this type of elevator is virtually to vary the camber of the combined tail plane and elevator surface, by means of which the pitching of an aeroplane in flight is controlled. If the incidence of the tail plane is adjustable, the range of control can be varied, and any desired fore-and aft trim can be maintained without constant pressure being exerted on the controls. Elevators usually have some form of aerodynamical balance, the conventional type being the horn balance. In some designs the horn balanced portion is shielded by the tail plane over the smaller angles of movement as indicated in fig. 64, or partly shielded. This latter arrangement is provided to avoid the snatch which is often evident when the leading edge of the balanced portion protrudes above or below the surface of the tail plane itself.

Fins and rudders.

30. Fins and rudders are provided in order to control the yawing of an aeroplane and give additional lateral stability. These surfaces are arranged vertically and usually form part of the tail unit. The fins are normally attached to a sternpost at the rear end of the fuselage, and are so positioned that, in conjunction with the rudder, they form aerodynamically a

variable camber aerofoil. The rudders are usually hinged to the sternpost and are sometimes aerodynamically balanced, the balanced portion being sometimes shielded by the fin over the smaller angles of movement. Normal arrangements of fins and rudders are shown in figs. 50 and 66. The object of the shielding is to obviate overbalancing which is possible during the first few degrees of movement.

Slots.

31. Slots are a device for varying the air flow over the surface of an aerofoil, by the use of an auxiliary aerofoil, or slat, set parallel to and in front of the leading edge of the main aerofoil. The slot is, strictly speaking, the gap between the main and the auxiliary aerofoils, the size of the gap being regulated by the movement of the auxiliary aerofoil. As the gap or slot is its essential feature, it has given its name to the device as a whole. Slats may be fixed, manipulative or automatic, and their use may be to increase lift of the wing, or to contribute to the lateral stability and control. The auto control slot is the type generally used on Service aircraft. This is a type which automatically opens when the incidence of the wing exceeds a given angle and closes when the wing returns to a given angle. Fig. 6A shows diagramatically a typical arrangement of an automatic slot in which the auxiliary aerofoil is free to take up any position as determined by the resultant force on the slot due to the incidence of the main aerofoil. Fig. 6B shows in diagrammatic form the lines of action of the resultant forces due to various angles of incidence of the main aerofoil. The action of the slot is that, when the main aerofoil is stalled or near stalling, the slat will be in a forward position, as indicated in fig. 6B, thus directing a flow of air through the slot and over the main aerofoil which mitigates the burbling or eddying taking place, which is characteristic of the unslotted wing at stalling incidence.

32. There are several conditions which appear to affect the successful functioning of the auto control slot, but the gap arranged between the trailing edge of the auxiliary aerofoil and the main aerofoil when the slot is closed would seem to be the most important. The amount of gap affects the opening point of the slot owing to the transference of the negative pressures from the upper side of the main aerofoil on to the underside of the auxiliary aerofoil.

AEROPLANES.

33. There are several types of heavier-than-air craft, but the type in normal use is the aeroplane. Aeroplanes can be classified under the headings of land planes, amphibians, and seaplanes, and the seaplane can again be subdivided into float planes and flying boats. Aeroplanes are usually either

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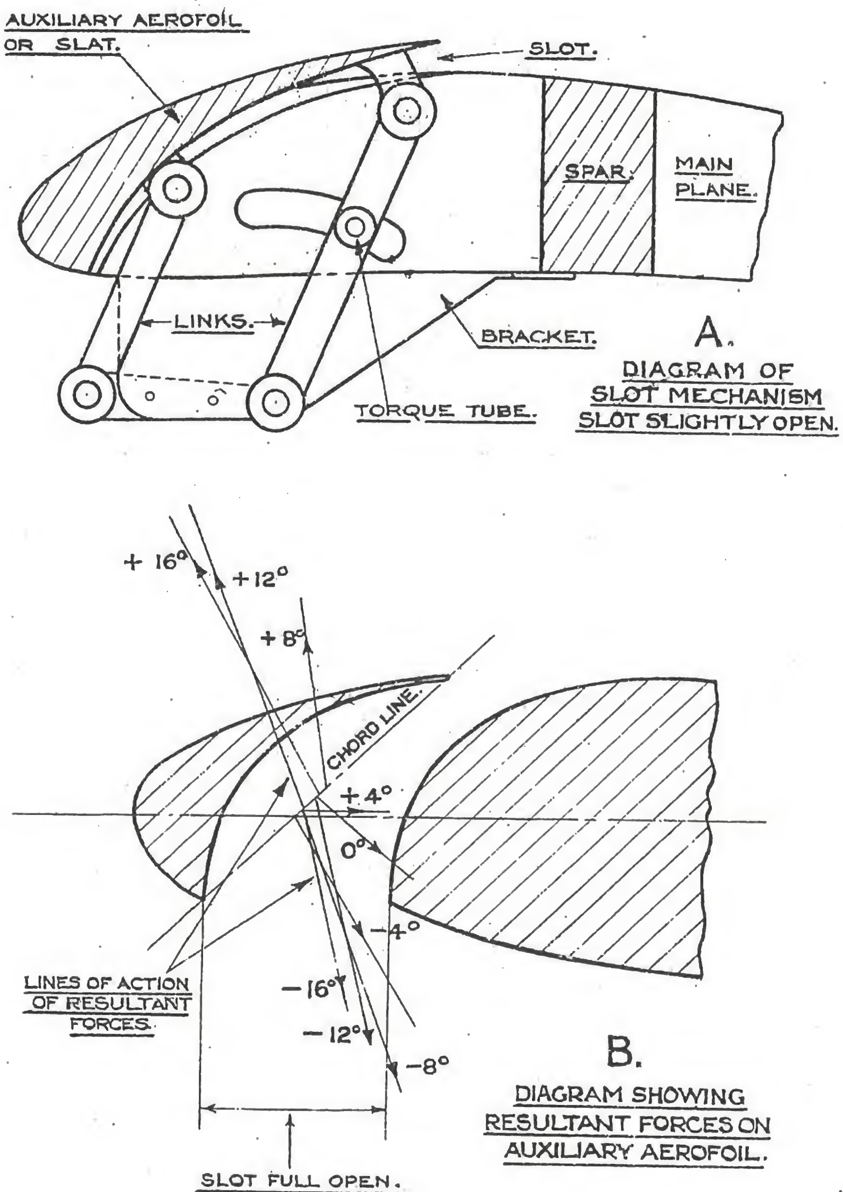

FIG. 6. AUTOMATIC SLOT DIAGRAM.

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Malby & Sons, Photo-Lith.

monoplanes or biplanes, although theoretically there is no reason why an aeroplane should not have as many supporting surfaces as desired.

Stability.

34. A stable aeroplane is one which tends to return to the same state of motion after disturbance, without movement of the controls by the pilot. An unstable aircraft is one which will not return to the same state of motion after disturbance without assistance. Longitudinal stability is the stability of the motions of the aeroplane in the plane of symmetry, that is, of the rise or fall, forward motion and pitching in the direct line of flight with the planes horizontal. Lateral stability is that of the motions of rolling, yawing and sideslipping, which always occur in combination. The longitudinal and the lateral motions can occur independently or they may occur together.

Yawing.

35. Yawing is the inclination from side to side of the direction of motion of the aeroplane out of the plane of symmetry, that is, turning about the vertical axis which passes through the centre of gravity of the aeroplane. and is normally controlled by the rudder.

Rolling.

36. Rolling is a movement usually controllable by the ailerons, and is the angular movement or turning of the aeroplane about the fore-and-aft axis.

Pitching.

37. Any movement in the plane of symmetry in which the aeroplane is turned about an axis through the C.G. perpendicular to the plane of symmetry is termed pitching, and is normally controllable by the elevators.

Nose and tail heavy.

38. When an aircraft has a tendency to lower or raise its nose in flight it is considered to be in a " nose heavy " or " tail heavy " condition. An aeroplane which is nose or tail heavy can usually be corrected by adjustment of the tail plane.

" One wing down."

39. This is an expression denoting that the aeroplane is out of trim laterally, and has a tendency for one wing to drop. This condition is generally due to incorrect rigging.

Slipstream.

40. The stream of air which is discharged aft by a revolving airscrew is termed the " slipstream." Particularly on single-engined aircraft, the slipstream very appreciably affects the

aircraft in flight, owing to the effect on the control surfaces of the tail unit and sometimes owing to the restricted space between the body and the centre sections of the planes. Special precautions have usually to be taken in securing all parts subjected to the effects of the slipstream.

Down-wash.

41. The current of air deflected downwards relative to the aeroplane by an aerofoil or other body is called the down-wash. In certain conditions it is possible for the down-wash of one plane to interfere considerably with the air flow of a plane below it.

Centre of gravity.

42. The position of the centre of gravity of an aeroplane is of very great importance and definitely affects the stability and controllability of the aircraft. The centre of gravity of an aeroplane is that point through which the resultant of the weights of all its component parts passes in any position that the body may assume. The position of the centre of gravity of an aeroplane is determined in the manner described in Appendix I of this publication. It is very necessary that the fore-and-aft limits for the position of the centre of gravity, as given in the certificate of airworthiness, should not be exceeded.

Drag (Total).

43. The total drag is the resistance induced by the aeroplane along the line of flight, and includes not only the drag of the planes, but also the parasitic drag of the fuselage, undercarriage, struts, and generator, etc.

Drift.

44. The drift of an aeroplane is the movement sideways or crabwise relative to the ground, usually caused by a side wind. Drift is usually measured as an angle between course steered and the actual ground track traversed.

Stalling Speed.

45. An aircraft is said to be at stalling speed when the airspeed is at the minimum necessary to support it in the air. In these circumstances the angle of incidence corresponds to the maximum lift coefficient of the planes.

Service ceiling.

46. The Service ceiling is that height at which the rate of climb has fallen to a certain defined limit (e.g., 100 ft./min.). The absolute ceiling is the limit of height attainable in standard atmosphere under specified conditions.

CHAPTER II.

TOOLS AND INSTRUMENTS.

TOOLS.

Tool kits.

47. The standard tool kit for metal riggers, as enumerated in Air Publication 830, Vol. III, contains all the hand tools normally required. In addition to these, occasional use will be found for other tools, all of which are available and can be obtained from the flight or headquarters lock-up, and which are also enumerated in the above publication. With a few exceptions, the tools need no explanation and will present no more difficulty in use than practice in the proper handling will overcome. Amongst the exceptions are the measuring tools employing the vernier principle, such as the vernier and micrometer calipers which are illustrated in figs. 7 and 8. The micrometer is normally used for measuring the diameter of cylindrical parts, whilst the vernier is generally used for measuring flatter objects. As instruments and tools employing the vernier principle are often used, the system should be thoroughly understood.

Vernier.

48. The principle of the vernier, which can be applied to any units of measurement, is as follows :—Referring to fig. 7, the long scale is stationary, while the short vernier is capable

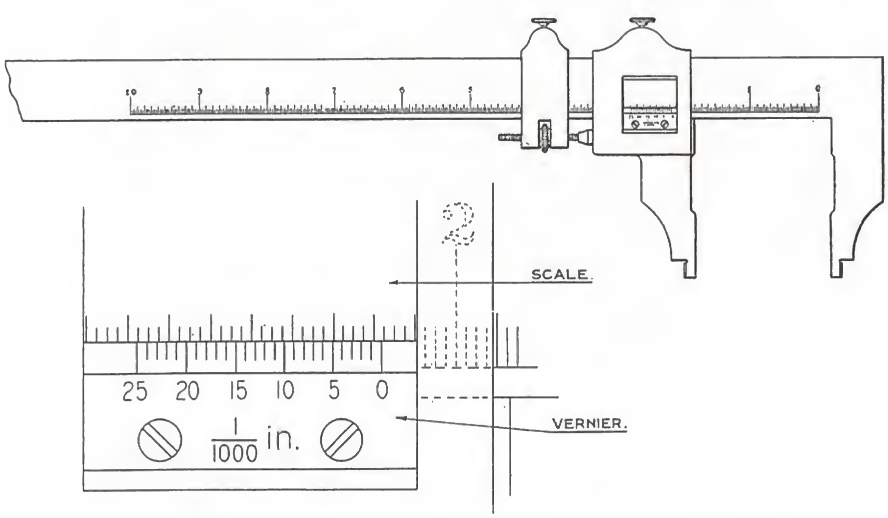

FIG. 7.—Vernier.

of being moved along the scale. Both the scale and the vernier are marked in regular divisions, but it will be noted that the vernier divisions are slightly shorter than the scale divisions.

49. Suppose, as is generally the case for the type of instrument illustrated, that each division of the scale is equal to 1/40th of an inch, and the vernier is equal in length to 24 of the scale divisions, but is divided up into 25 parts. If the vernier is so placed that the end lines of the vernier exactly coincide with the end lines of 24 divisions of the scale, then the first division line of the vernier will not be exactly opposite the first division line of the scale, but will be out of line to the extent of 1/25th of 1/40th, which equals 1/1000th of an inch. The second division will be twice this, or 2/1000ths out of line, and so on to the end of the vernier, when the difference will be 25/1000ths or one complete division of the vernier. So, obviously, if the vernier is moved until the first subdvivision line is opposite the first on the scale, then the vernier will have moved 1/1000th in. or ·001 in. If the vernier is progressively moved along the scale in the same direction, it will be noted that each subdivision of the vernier will in succession agree with the next subdivision on the scale, but none of the other vernier lines will coincide with any of the lines on the scale. Therefore, when making a measurement, it is necessary to observe the lines which coincide in order to determine the thousandths.

50. Now, referring to the complete tool in fig. 7, it will be seen that both the scale and the vernier are marked 0 at one end. When taking the measurement of an article, a note is made of the distance, in inches, tenths, and fortieths of an inch, that the 0 marked on the vernier is from the 0 marked on the scale. Multiply the number of fortieths by 25 to reduce them to thousandths and add this dimension to the inches and tenths. Then observe the line on the vernier which most closely coincides with any line on the scale, and add this reading in thousandths to the previous figures. In the example illustrated, a measurement is taken between the jaws of the tool, and the 0 on the vernier has moved to a position equivalent to 2 in. + 1/10 + 3/40. The seventh line on the vernier agrees with a subdivision line on the scale, so that the reading will be 2 in. + ·1 + ·075 + ·007 = 2·182 in.

Micrometer.

51. Fig. 8 gives an illustration of the two usual forms of micrometer. The same method is used for reading both these tools, but one is for inside and the other for outside measurements. The movement of a micrometer is rotary, and the

measurements are made between the anvil and an extensible screwed spindle. To the spindle is attached the rotating sleeve or thimble. The pitch of the thread on the spindle is

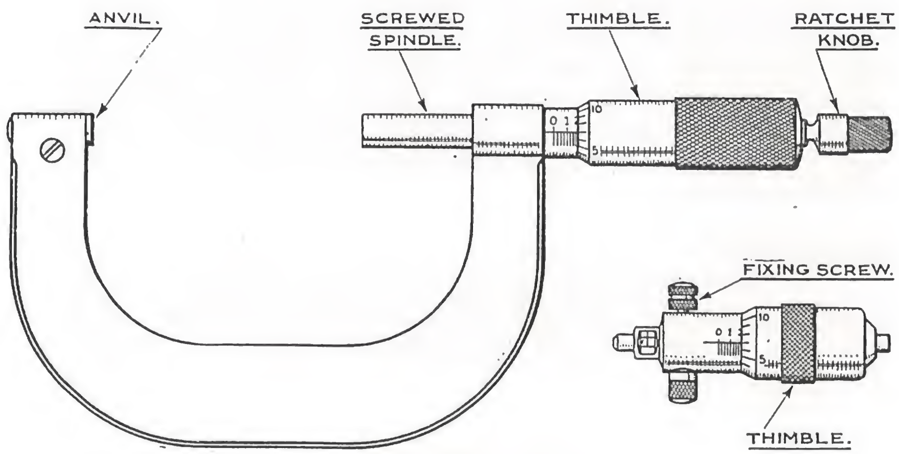

Fig. 8.—Micrometers.

40 to the inch, so that one complete turn of the rotating thimble is equal to an axial movement of 1/40th in. = ·025 in. The number of turns given to the spindle is indicated on the graduated scale marked on the inner stationary sleeve. This scale is marked off in fortieths of an inch, each fourth division mark being elongated to represent the 1/10th. The bevelled edge of the rotating thimble has 25 divisions, each fifth line being marked progressively from 0 to 25.

52. If the thimble is rotated one subdivision, this is obviously equal to an axial movement of 1/25th of 1/40th, which is equal to 1/1000th or ·001 in. When taking a reading, the size of the micrometer is noted and the minimum dimension to which it will measure is taken. The number of 1/10ths visible on the stationary spindle is also noted. Then the number of subdivisions, or fortieths, of the last incomplete tenth are multiplied by 25 to reduce them to thousandths, and to these dimensions are added the number of subdivisions on the thimble, from the 0 to the line which coincides with the horizontal line on the stationary sleeve, all the figures added together giving a dimension to the nearest 1/1000th of an inch. As an example, if the micrometer is a 2 in. to 3 in. size and the position of the spindle is such that 1/10th division and three subdivisions are shown on the sleeve, and the 7th division on the thimble agrees with the horizontal line, then the measurement will be 2 in. + ·1 + ·075 + ·007 = 2·182 in. With practice, a still finer reading may be taken, by judging the

position of the horizontal graduated line, when this line is between two marks on the thimble.

53. Of the two types of calipers described, the micrometer is considered to be more consistently accurate than the vernier, and is less subject to damage. It is neither necessary nor advisable to use any force when taking a measurement with either the micrometer or the vernier. Some makes of micrometer have a ratchet actuating knob provided at the top of the thimble to ensure that a light but consistent pressure is used.

Special tools.

54. Special tools will be required at times for repairs and similar work, and their uses are described in the appropriate publications, such as the Repair Notes for the particular type of aircraft.

INSTRUMENTS.

Straightedge.

55. The best form of straightedge which can be relied upon to keep reasonably true is made of solid metal, usually steel, and is available in lengths up to 6 ft. In the largest sizes, their cost and weight make them unsuitable for rigging purposes; therefore hardwood straightedges are generally employed. If this form of straightedge has been carefully made in the first instance and frequently tested during use, it is sufficiently accurate for all rigging purposes.

56. Care must be exercised in storage and in use, and, if not used for some while the straightedge must be tested for accuracy. Teak and mahogany are amongst the best materials from which to make wooden straightedges, but brass protection strips should be placed on the ends, and in other positions where excessive wear or damage is anticipated.

57. It is not possible to use straightedges on all occasions when the function of a straightedge is required. Under these conditions it is usual to employ a length of thin strong balloon cord or similar material tightly stretched between the objects to be levelled, or between the points of reference. The sag or dip can be quite appreciable, and it is advisable, if comparatively long distances are involved, to try the cord first by tying one end to some fixture, and holding the other end in the hand at a distance approximating to that required, and sighting along the cord for sag. By this means, the tension required on the cord is ascertained. For the smaller aeroplanes greater accuracy can be obtained by using No. 18 white thread, Stores Reference 32B/451, than by using cord.

Trammels, truing. Stores Ref. 1c/2593.

58. A set of trammels is an almost indispensable part of the rigger's equipment. As shown in fig. 9, trammels are simply metal fingers arranged to slide easily but without shake along a wooden bar with a screw by which the trammel can be fixed in any desired position. A pair of trammels is used

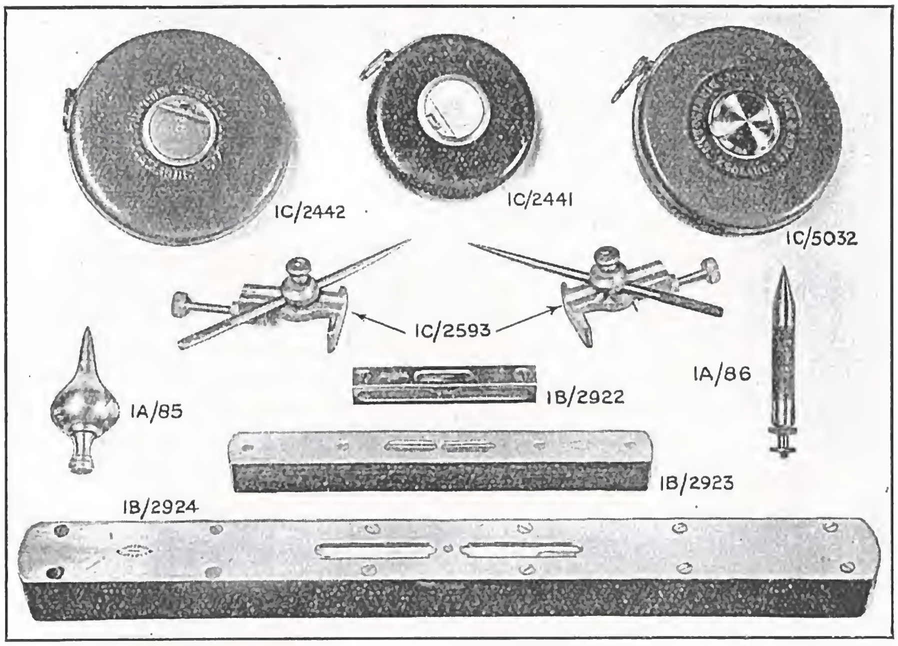

FIG. 9.—Rigging instruments.

chiefly to compare two or more distances which should be equal, such as the cross bracing wires of an undercarriage or fuselage, but is also useful to measure distances which are inaccessible to the usual steel measuring tape. It is not unusual to have two or three beams of varying lengths, made to fit the same trammels.

Bobs, plumb (8 oz. and 3½ oz.). Stores Ref. 1A/85 and 86.

59. A plumb bob is used by the rigger as the special form of weight at the end of a cord to form a plumbline. Plumblines are used to ascertain by visual comparison if the object to be lined up is truly vertical. A plumb bob is provided with a point at the lower end by means of which the plumbline can be placed directly over a point or line. A plumbline will always give a truly vertical line from its last point of contact. The two forms of plumb bob issued are shown in fig. 9; the

heavier of the two is made of brass and weighs 8 oz.; the other is mercury-filled and weighs $3\frac{1}{2}$ oz.

Levels, spirit, 4 in., 10 in. and 18 in. Stores Ref. Nos. 1B/2922, 2923 and 2924.

60. A spirit level is an essential part of a rigger's equipment, as by its use an object can be made truly horizontal. One or more of the types shown in fig. 9 will normally be available for the rigger. It is generally advisable to use a straightedge in conjunction with the shorter types of spirit level if the part to be levelled is long, or the points of reference are far apart. Spirit levels must be treated with care, as otherwise the glass bulb will be displaced or broken.

Level, adjustable, 0° to 10°.

61. Incidence and dihedral angles are usually ascertained by means of special boards provided for each type of aeroplane. When these boards are not available, it is necessary for the rigger to have an instrument which is suitable for quickly and accurately determining these angles. The instrument usually supplied is a special form of adjustable level or inclinometer. There is now being developed a new type of adjustable level designed to measure from 0° to 10°. This instrument, which is

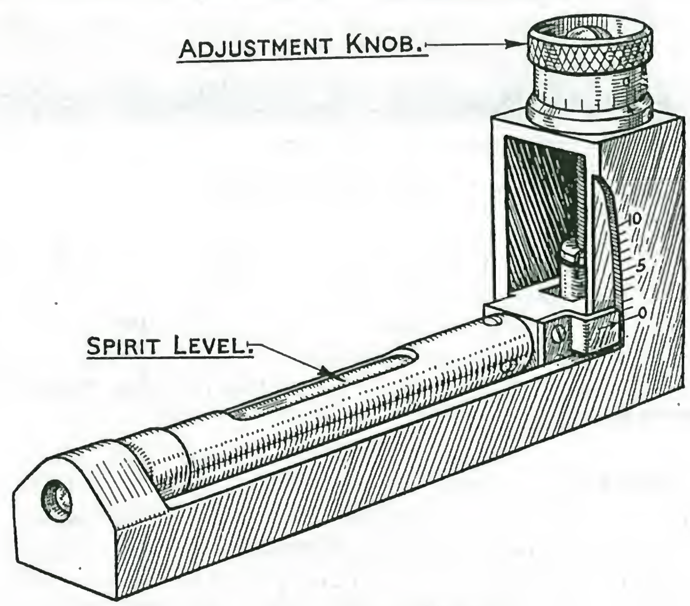

FIG. 10.—Adjustable level.

shown in fig. 10, consists of a base with a bridge piece at one end, a levelling arm which contains a spirit level, and a knurled drum which is rotated to raise or lower the

levelling arm. Attached to the levelling arm is a pointer, which registers with graduations marked in degrees on the outside of the bridge piece. The knurled actuating drum is marked off into 12 divisions, and, as each division is equal to five minutes, one complete turn of the drum is equal to one degree.

62. In order to measure an angle (of 10° or less), the instrument should be used in conjunction with a straightedge in the usual manner, and the knurled actuating knob rotated until the bubble of the spirit level is central. The degrees are then read from the side graduations, as indicated by the levelling arm pointer, and the minutes from the actuating drum as given by the arrow marked on the collar immediately below it.

CHAPTER III.

FURNITURE AND EQUIPMENT.

63. The standardisation of R.A.F. ground equipment to be suitable for all types of aircraft and also to fulfil all requirements is a difficult matter, owing to the introduction of new types of aeroplanes and new methods, but all equipment is under constant review with the object of modernising and, whenever possible, rendering it of universal application. Items of equipment are introduced and standardised from time to time as occasion warrants, under authority of an Air Ministry Order. Air Publication 1086 gives a priced vocabulary of all Air Ministry stores, including all rigging equipment.

64. Many items of equipment now in service are extemporised or are obsolescent, and no further purchases or renewals of these items will be made. The items of equipment described in this chapter are those which appertain to rigging only and are those which are standardised, or about to be standardised, and which will replace existing equipment as renewals become necessary. Proprietary articles or items peculiar to a particular type of aircraft are not mentioned.

Bench, Carpenters. Stores Ref. 4A/6.

65. This bench is intended for squadron or flight use, and is capable of being rapidly dismantled and reassembled. A woodworker's vice is fitted in addition to the usual planing stops, etc.

Bench, fitters. Stores Ref. 4A/7.

66. The construction of this bench is similar to that of the carpenter's bench, but has a level and thicker top. Attached to the bench is a fitter's vice, Stores Ref. 1C/2609, or an armourer's vice, Stores Ref. 1C/2620, in accordance with the use for which the bench is intended.

Boards, aeroplane serviceability. Stores Ref. 4A/449.

67. These boards consist of a binder for Form 535, with an attached flap. The flap is arranged to turn over so as to exhibit either " S " or " U " on both sides of the board. The boards are hung on to the aircraft immediately a defect is noted or reported in accordance with the instructions for maintenance and inspection of aircraft, K.R. & A.C.I., para. 702.

Chocks, aeroplane wheel, wood, general purposes. Stores Ref. 4A/193.

68. The ordinary standard wooden chock for station use is shown in fig. 12. It is to be constructed by units.

TABLE I.

A.P.1086. Section No.	Ref. No.	G Stores D.I.S. No.	A.M.W.O. or A.M.T.O.	Description.	Remarks.
4A	6	25	T.O. 69/26	Benches, carpenter.	
4A	7	16	T.O. 69/26	Benches, fitters.	
4A	449		W.O. 25/29	Boards, aeroplane serviceability.	
4A	545 to 568			Block, tackle ..	Various sizes to take $1\frac{1}{2}$ in. to 4 in. Cordage.
4A	193	25	T.O. 69/26	Chocks, aeroplane Wheels, wood. G.P.	
4A	520		T.O. 204/28	Chocks, aeroplane Wheels, Metal, collapsible.	
4A	450		W.O. 25/29	Desks, flight.	
4A				Jacks, lifting ..	Various types.
4A	259			Ladders, extension	14 ft. to 32 ft.
4A	86	104		Ladders, flat top ..	6 ft.
4A	91	103		Ladders, shelf ..	10 ft.
4A	98	102		Ladders, swing back, 6 ft.	
4A	97	112		Ladders, swing back, 8 ft.	
4A	95	115		Ladders, swing back, 12 ft.	Flat top.
4A	94	110		Ladders, swing back, 14 ft.	Flat top.
4A	333	61	T.O. 169/26	Mats, centre section.	
4A	412		T.O. 205/28	Skates, side tracking, tail.	
4A	413		T.O. 205/28	Skates, side tracking, with chock wheel.	
4A				Tackles differential	Various sizes from 5 cwt. to 10 ton.
4A	440	154	T.O. 634/30	Trolley, aerodrome.	
4A	149	272/4		Trestles, rigging ..	16 ft. 10 in.
4A	411	140	T.O. 71/29	Trestle, tail.. ..	Adjustable, 3 ft. 8 in. to 5 ft., tripod pattern.

Chocks, aeroplane wheel, metal (collapsible). Stores Ref. 4A/520.

69. These chocks are made as light as possible and in the form shown in fig. 12, in order that they may, when necessary, be carried on the aircraft in flight. This type of chock is intended mainly for use abroad.

Tackle, differential, 1 ton (fixed). Stores Ref. 4A/739.

70. Several types of lifting tackles and cranes other than the one enumerated above are in use at various units. The lifting tackle shown in fig. 12 is the ordinary type of chain gear and needs no description. In addition to the present standard types, there is a new tripod type which may be standardised shortly. It is shown in fig. 14, and described in para. 90.

Desks, flight. Stores Ref. 4A/450.

71. Flight desks are to be made up locally to the dimensions given in Air Ministry Weekly Order 25 of 1929. They are for use as notice boards and also in connection with the serviceability board, maintenance forms, etc.

Jacks, lifting.

72. A number of types of jack are in service which have been standardised for use under special conditions but are not of universal utility. These jacks are listed in Air Publication 1086 in Sections 2 and 4. In addition to these jacks, there are two new types which may be standardised shortly; these will be more universal in character and may replace some of the existing types as renewals become necessary. The new type of jack is described in paras. 87 and 89 and illustrated in fig. 13.

Mats, centre section. Stores Ref. 4A/333.

73. During overhaul, inspection, refuelling and other similar operations, it is necessary to guard against injury to the fabric and structure. For this purpose special mats are supplied which can be placed in any position desired and there secured. The mats consist of a series of wooden slats which are attached to large squares of canvas. A similar type of mat is used for the protection of seaplane floats under similar conditions.

Skates, side tracking, wheel and tail. Stores Ref. 4A/413 and 412.

74. Side tracking skates are required when it is necessary to move an aeroplane sideways in a restricted space. Both types of skates are provided with castoring wheels, and the wheel type of skate is also provided with hinged chocks either end, which can be swung over and in that position act as ramps, as shown in fig. 12.

Trestles, rigging.

75. A large variety of different types of fixed wooden rigging trestles now in service have been made up locally to standard designs or to suit special circumstances. A number

of these trestles will be obsolete upon the introduction of the new type of adjustable steel trestle described in paras. 80 to 84. The hinged ladder type of rigging trestle with staggered rungs, Stores Ref. 4A/149, which is used for supporting planks during rigging operations, will remain as a standard item of equipment, and is shown in fig. 11.

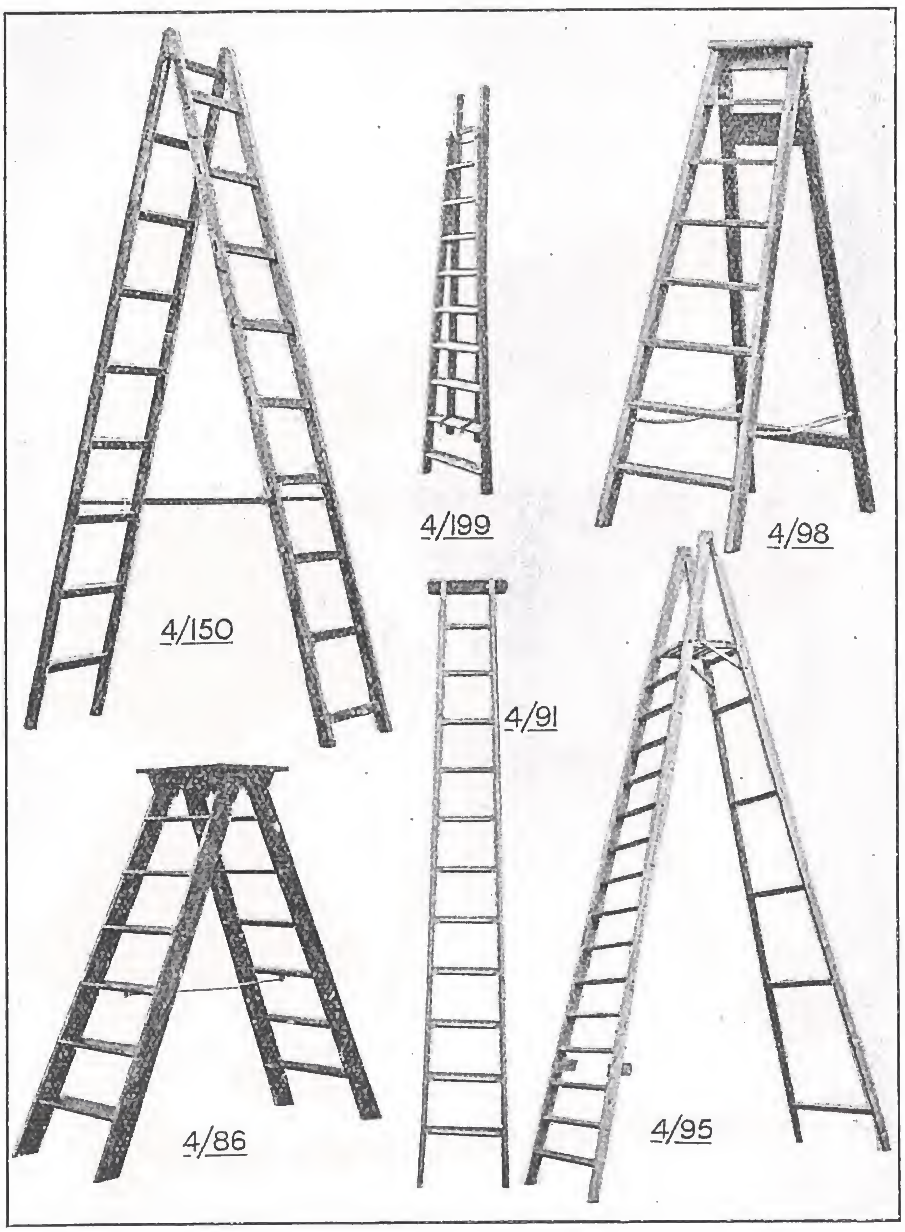

FIG. 11.—Ladders.

Ladders.

76. The standard types of ladders used by R.A.F. units are enumerated in table I, and illustrated in fig. 11. There are several sizes of each type, particulars of which are given in Air Publication 1086, section 4A.

Trestles (adjustable, tripod type, tail). Stores Ref. 4A/411.

77. This trestle is of great assistance for supporting the tail end of the fuselage when in rigging position. As will be seen from fig. 12, the trestle is all-metal, with the exception

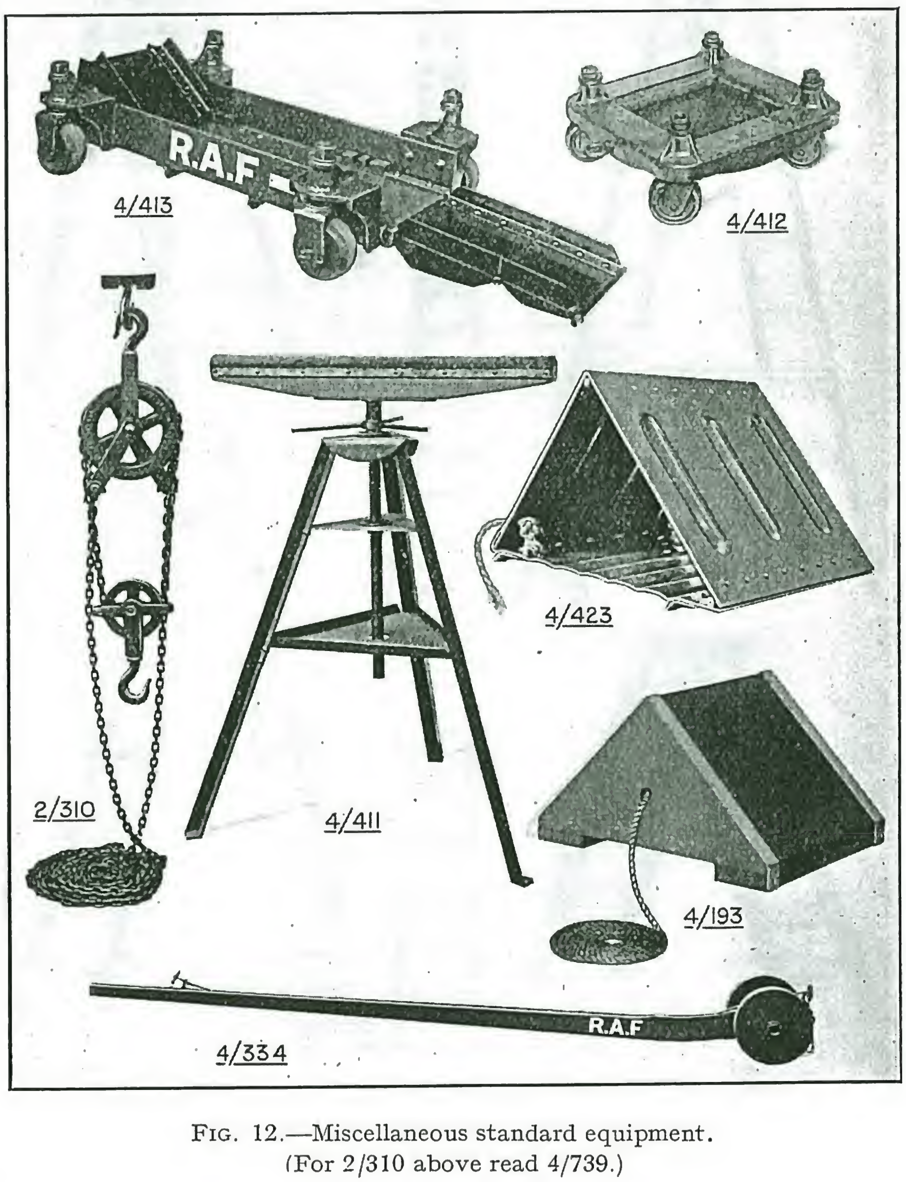

FIG. 12.—Miscellaneous standard equipment.
(For 2/310 above read 4/739.)

of the felt-covered ash bearer bar. It consists of three legs connected at the top by a sheet steel plate taking an adjustable ram, and braced by another steel plate about half-way down, made in the form of a tray. The trestle has an adjustable height range of from 3 ft. 8 in. to 5 ft. and will deal satisfactorily with loads up to 500 lb.

Trolleys, tail skid and aerodrome.

78. Several patterns of tail skid trolleys are in service, the type used depending upon conditions of usage and the weight and type of aeroplane. One of the existing standard tail skid trolleys for land stations is the lever type, shown in fig. 12. The type of trolley used on aircraft carriers is usually the scoop type, but here again special trolleys are often required for the particular aircraft being handled. In addition to the types which have been mentioned, there are two new types being produced which will probably be standardised at an early date, and are intended to supersede existing types. These trolleys are described in paras. 85 and 86 and illustrated in fig. 13. An aerodrome trolley, Stores Ref. 4A/440 (G. Stores 154), has been standardised for carrying night-flying equipment. The trolley has four wheels, the front two of which are steerable, and a wooden top platform suitably boxed to take the equipment. In its original form the trolley was fitted with aero wheels, but in the later approved pattern the " Trojan " pneumatic-tyred wheels are used.

NEW EQUIPMENT.

79. In addition to the standard equipment listed in Air Publication 1086, there are a number of new items of ground equipment which will be introduced as soon as the necessary investigations have been made to ensure the utmost serviceability and universal application. The new types of equipment are described below, but units are not to indent for any of these items until they have been introduced by an Air Ministry Order.

Trestles, jacking, universal.

80. The small wooden types of fixed trestle, of which there are a number of different kinds in use, will be replaced eventually by an adjustable steel type shown at E, fig. 13. It is intended that these trestles shall be issued in component parts, but all having the same form of jacking heads. This

form of trestle has the advantages that all the parts are interchangeable, and that it can be easily dismantled when not in use, and therefore is easily packed away or transported. If necessary, the existing legs can be replaced by legs of any reasonable length desired which are cut off from standard angle iron, drilled, and attached to the jacking heads. These trestles, when used on an aircraft carrier, will be fitted with detachable friction pad feet.

81. Given below is the trestle assembly table, which states the dimensions and parts required for making up trestles of various heights and widths.

TABLE II

No.	Height. Ft.	Height. In.	Width. Ft.	Width. In.	Legs.	Cross Stays.	Bottom Rails.	Diagonal Stays.
1	2	3	2	7	C	None	D	E
2	3	0	1	9	D	C	C	E
3	3	0	3	2	D	C	E	F
4	3	7	2	7	E	C	D	F
5	3	7	4	1	E	C	F	G
6	3	7	5	2	E	C	G	H
7	4	5	3	2	F	D	E	G
8	4	5	6	0	F	D	H	I
9	5	5	3	2	G	E	E	H
10	6	3	4	1	H	F	F	I

82. The length between bolt holes of various members equivalent to the letters given are :—

TABLE III.

C.	D.	E.	F.	G.	H.	I.
ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.
1 $8\frac{13}{16}$	2 $7\frac{3}{16}$	3 $1\frac{1}{2}$	4 $0\frac{13}{16}$	5 $1\frac{9}{16}$	6 $0\frac{1}{16}$	7 3

83. The height given is the minimum height when using a 4 in. by 2 in. ash cross bar. An angle iron of the same dimensions as the bottom rail may be used in place of the wooden cross bar if required. In this case the minimum heights given will be reduced by about 3 in. The range of adjustment of the jacking head is 12 in.

84. The loads these trestles will sustain, using the 4 in. by 2 in. ash cross bar, are dependent upon the type of load, and are approximately as follows :—

TABLE IV.

Size of Trestle.	Load Concentrated in Centre.	Load Equally Distributed	Load Divided between 2 Supports.
	lb.	lb.	lb.
1	1,500	3,000	13,500
2	2,240	4,480	12,320
3	1,120	2,240	12,320
4	1,500	3,000	11,200
5	1,000	2,000	11,200
6	900	1,600	11,200
7	1,120	2,240	10,000
8	675	1,350	10,000
9	1,120	2,240	8,900
10	1,000	2,000	7,040

Power tail trolley.

85. Power-driven tail trolleys will shortly be available for use with aircraft of the heavier types. There will be two sizes issued similar in general outline to that shown in fig. 13C, which is a photograph of the smaller size. The trolley is motor-driven, and has caterpillar wheels near the lifting arm and a castoring wheel at the opposite end of the trolley near the control handle, as will be seen by reference to the illustration.

Trolley, tail skid, hand.

86. Trials are being made with a view to producing for Service use a small hand-operated caterpillar tail trolley of the type shown in fig. 13D. This trolley is suitable for loads up to about 600 lb., and should, therefore, be suitable for all the smaller types of aircraft.

Jacks, high lifting.

87. In many instances where suitable lifting tackle is not available, there is a considerable waste of time owing to the height to which the aeroplanes have to be lifted, necessitating in many cases the use of duplicate jacks and packing blocks. To obviate this, a high lifting jack similar to that shown in fig. 13F will shortly be available for issue.

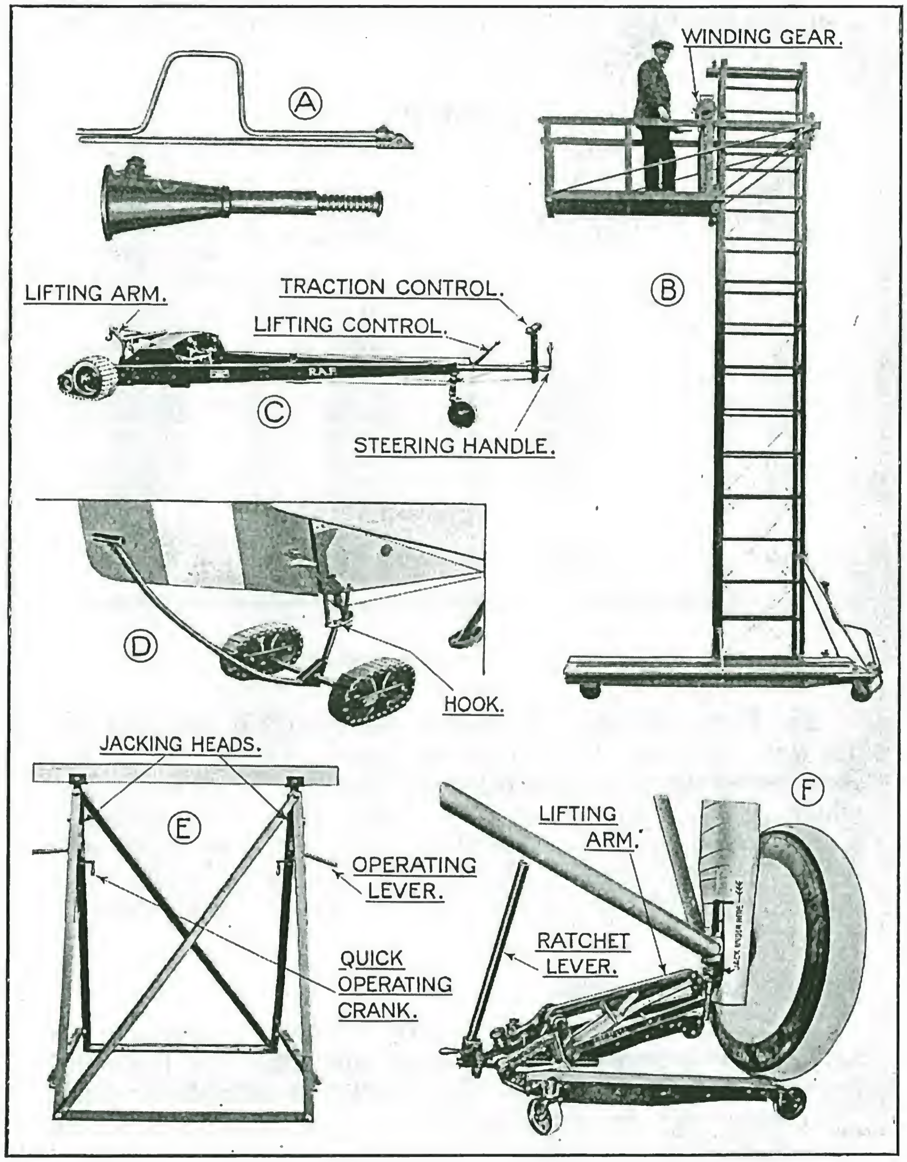

FIG. 13.—New equipment.

Ladders, tower.

88. When large aircraft are being dealt with, there are often occasions when it is necessary to examine the upper planes, or perform similar operations necessitating a self-supporting ladder of rather larger dimensions than is the standard equipment at most stations. The type of ladder

To face page 31.

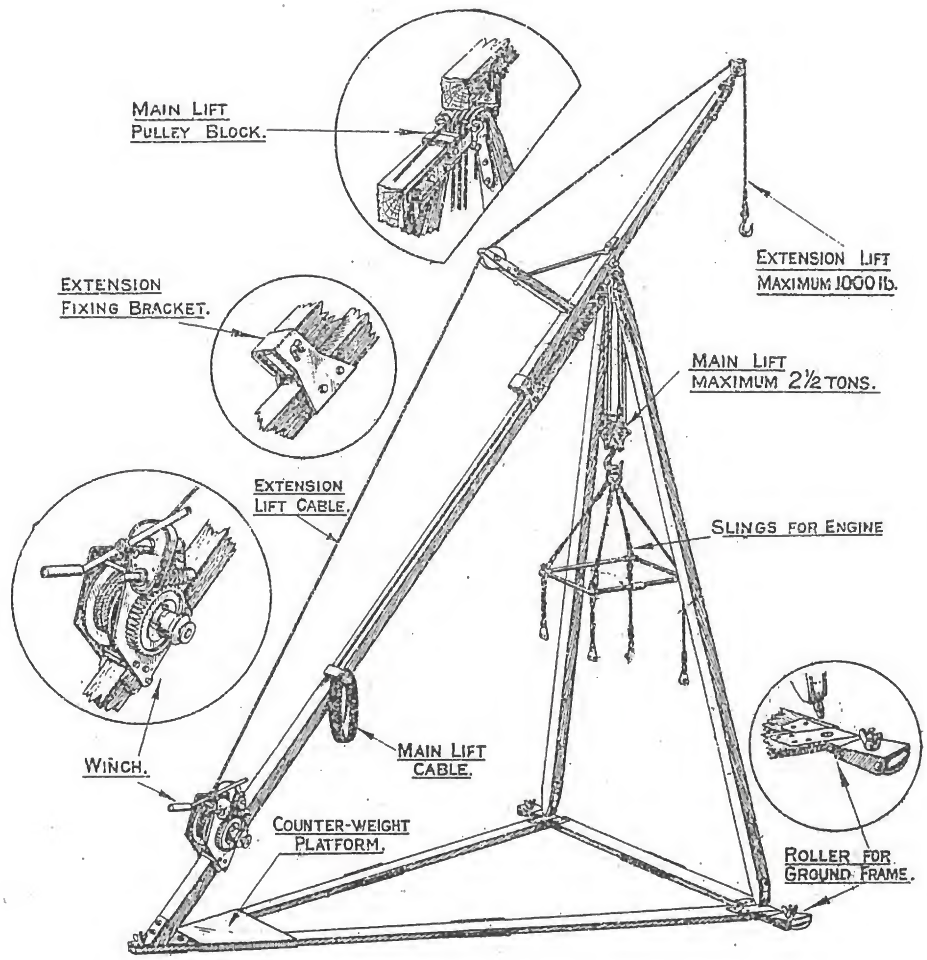

FIG. 14. SHEER LEGS.

P3682.

Malby & Sons, Photo-Litho.

which it is proposed to standardise for this purpose is illustrated at B, fig. 13. As indicated, the ladder consists of a vertical, square-section, braced structure, with a hand-operated platform which can be raised to any desired height by means of the winding gear shown. The tower ladder is suitably mounted on a trolley.

Jacks, lifting, universal, two-ton.

89. The two-ton screw jack shown at A, fig. 13, is a new type which may shortly be introduced into the Service for general purposes. This jack is similar in principle to many existing types, and therefore requires no description. As shown, a detachable, cranked operating handle, hinged in the centre with a universal joint, is supplied for raising the jack. The weight with handle is between 11 and 12 lb., and it is therefore sufficiently light to be carried on an aeroplane in flight. Special attachments are needed when used for aircraft purposes.

Sheer legs.

90. Light and handy forms of tripod lifting tackles are now being tried out with the object of standardising this form of crane for Service use. In one type, all the members constituting the tripod are of wood, and, as will be seen from fig. 14, the main lifting tackle operates from the apex of the tripod ; but for lifting smaller loads to a greater height a wooden arm extends beyond the apex and carries a pulley over which one end of an auxiliary lifting cable runs. The other end of this cable passes over a pulley on a kingpost and down to the drum of the winding gear. When using the extension arm, the crane is capable of lifting 1,000 lb. Another type is constructed entirely of metal, and is suitable for conveyance by air. This type is of simple design and construction, and consists of two splayed legs carrying a braced jib at the apex. The jib is made from tubular material, and is suspended from a central kingpost, with tie rods between the kingpost and the ends of the jib. To one end of the jib is attached the block lifting tackle, and to the other end is connected a back stay and two side stays. The back stay is secured to a picket stake and the two side stays to the lower ends of the legs. The construction, which is mainly of duralumin, allows of a weight of 1,000 lb. being lifted through a maximum distance of approximately 18 ft. The total weight is approximately 180 lb.

CHAPTER IV.

PRINCIPLES OF CONSTRUCTION.

General.

91. The man who is concerned with the flying or maintenance of an aircraft is not usually in a position to work out the stresses in the various members, and he must therefore take these on trust, but it is very desirable that he should understand the more important underlying principles of construction of the aircraft with which he is in daily contact.

Basic considerations.

92. An aircraft is designed and built in accordance with a specification for the type. The specification contains all the requirements to be met by the designer, and on these he bases his calculations. The requirements laid down are, broadly, the duties and performance, load to be carried, and the horsepower available, and these are the main facts which determine the total weight and size of the aircraft, and which influence the designer in his selection of wing section, area, span, and general arrangement. There are many other considerations, both aerodynamic and structural, which have to be thoroughly thought out and understood before the design of an aircraft can take definite shape.

93. The basic principles of construction of an aircraft is that the maximum strength should be developed with the minimum weight of materials and resistance in flight. The attainment of this object is limited by such considerations as cost of materials and labour, and economy in manufacturing processes. Questions such as the durability and reliability of the materials and possible defects in workmanship affect the details of the design, and have also to be considered, but the principle of strength for weight must occupy the most prominent place.

94. The first problem of the designer is to ascertain, as accurately as possible, the maximum loads and stresses which may be encountered by the different parts of the aircraft. The second is to provide a structural arrangement capable of sustaining these loads and built in the lightest possible way. On the whole, aircraft structures follow accepted engineering principles, although the assumptions and the formulae used for heavy engineering are not always sufficiently accurate for aircraft strength calculations. In practice, the design and construction of aeroplanes present many problems, which are only solved by the closest investigation at the difficult points, making many tests, and paying great attention to accuracy of detail.

Strength of materials.

95. The strength of a material is generally quoted as that load in pounds or tons per square inch of cross-sectional area that it will withstand when placed in tension. The figure quoted is sometimes given as the "ultimate strength," or the load per square inch at which the material would break under test, and sometimes as the "proof stress" or "yield." The yield is not often quoted for aircraft use, because it is not

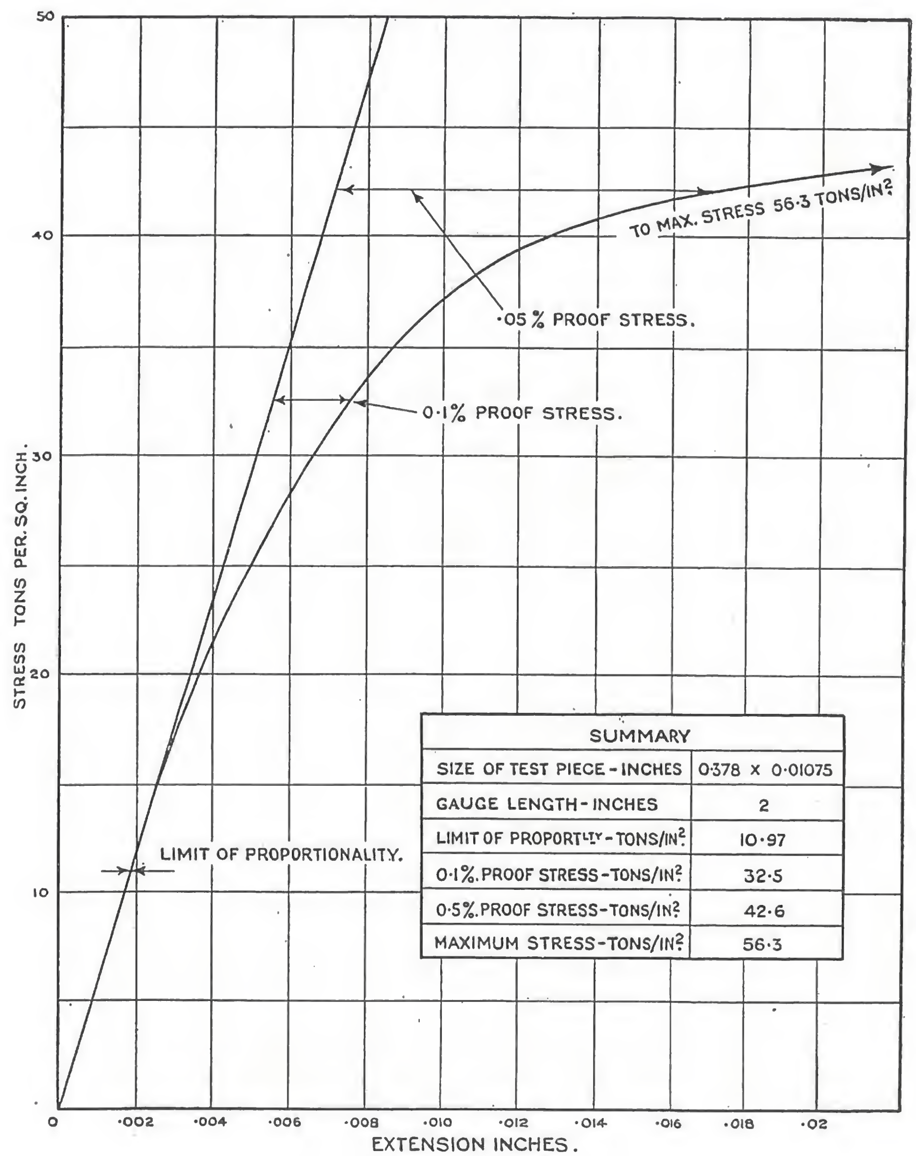

FIG. 15.—Stress extension curve.

sufficiently definite; therefore the term proof stress is preferred. The proof stress may be taken to be that stress which causes a permanent extension in a test specimen, the extension being some agreed percentage of a gauged length, usually 0·1 per cent. to 0·5 per cent. This is made clearer by reference to fig. 15, which is a stress-extension curve plotted from the results of a tensile test of a steel specimen, with the stress as ordinates or vertical measurements, and the extension as abscissae or horizontal measurements.

96. The "limit of proportionality" which is sometimes alluded to is that point on a stress-extension curve where the stress and the extension cease to rise in proportion, that is, where the curve ceases to be straight. This point is also defined in fig. 15.

Fatigue failure.

97. Fatigue failures are caused by the repeated application of comparatively small loads to parts, particularly which have sudden changes of section, such as may be produced by bolt holes, abrupt shoulders, notches, or even deep scratches. The failure is caused by the formation and growth of a crack, and the fracture has a characteristic appearance involving little or no local deformation, such as occurs in a static tensile test of the type described in para. 102. The fractured surface usually has a crystalline appearance, but this must not be taken to mean that the material has altered its internal structure, the appearance being caused by the irregular path taken by the growing crack.

98. If a part, such as that given in fig. 16, is subjected to a tensile load, the stress in the material at the reduced section is no longer uniformly distributed, and will become considerably concentrated in the immediate neighbourhood of the hole. This is indicated by the lines drawn in fig. 16 which represent the approximate stress distribution. Under load, if the material is reasonably ductile, the small portion affected by the stress concentration occasioned by the hole may just exceed the limit of proportionality stress and deform plastically, before the average stress over the whole section has reached a high value, thereby tending to equalise the stress over the whole section. Under these conditions no failure will result.

99. If a similar stress is intermittently applied at a rapid rate, the material has no longer an opportunity of deforming plastically, and a small crack may form. This crack itself acts as a notch with a still greater concentration of stress at its base, and the crack may therefore continue to spread and finally cause a fatigue failure.

Stress.

100. The direct stress in a member is the ratio $\frac{\text{load}}{\text{area}}$, or the load in pounds or tons, divided by the sectional area of the member in square inches. As an instance, if a specimen with a sectional area of 1 sq. in. is given a tensile load of 10 tons, then the stress is 10/1, or 10 tons per sq. in. If the specimen were only a half a square inch in area, then the stress would be $10/\frac{1}{2}$, or 20 tons per sq. in., and, conversely, if the area were 2 sq. in. the stress would be 5 tons per sq. in.

101. Up to the limit of proportionality, any member or specimen which is given a progressive tensile load will extend in direct proportion to the load applied, and, if the load is taken off, will return to practically its original length. This is the normal range of stress for any material under working conditions.

102. If the loading is taken beyond the limit of proportionality, the specimen will receive a permanent set, that is, if the load is released it will be found that the specimen is longer than it was originally. If the loading is continued until the specimen fails, considerable elongation will have taken place, the amount depending upon the ductility of the material. A good quality mild steel will extend at least 20 per cent. (about 1·6 in. when using a test specimen 8 in. long), and the area of any section of the specimens will have decreased proportionately, a very marked reduction in area being noticeable at the point of failure.

103. When a flat straight member, such as that shown on fig. 16, has a hole through the flat side, and is placed under a tensile load, the stress is greater across the section containing

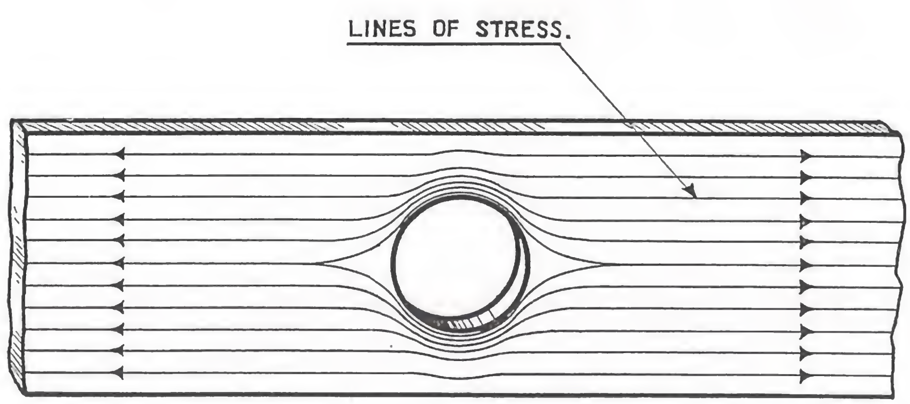

FIG. 16.—Lines of stress in a drilled bar under tension.

the hole than elsewhere, owing to the reduction of area at this point. That is, if the bar is 1 in. wide, and has in it a half inch diameter hole, then the stress would be doubled because the area is halved. The term " stress," as used above, is to be understood to imply " mean stress " or the average stress over any section taken through the test piece or member being considered. The stress in a member is not always evenly distributed over the section, but owing to irregularities in the material may be greater in one part than another. Referring again to fig. 16, the actual stress in this instance would be greater in the immediate vicinity of the hole than elsewhere, owing to the fact that the stress is diverted from the centre round the hole, as indicated by the lines of stress shown. The intensity of the mean stress of any part of a member under load can be fairly accurately estimated up to the point when the material commences to yield ; after this point the material reaches what is termed the plastic stage when the stress distribution is very problematical. Stress may be tensile, such as is found in bracing wires, or it may be compressive, as exemplified by struts, or shear, as encountered in pins. A tube or rod which is being twisted is also subject to shear.

104. The different ways in which the parts of an aircraft are stressed should at all times be studied, and it is a good exercise to examine the aircraft with this object in view. As an example, take the rather complicated stresses in the spars. The air pressure on the fabric produces a load on the bottom plane spars which is transferred by the struts and flying wires to the upper plane spars, and, by virtue of the lift wires, gives compressive stresses to these members. These stresses are again reduced or increased by the tension in the front, and compression on the back spars, caused by the drag of the wings. The ideal condition is that all parts should be proportionally stressed and employed as near their final strength as is compatible with safety.

Load factors.

105. The safety of an aircraft is dependent upon the maximum stress in the various members being lower than the ultimate stress of the materials from which they are made. The maximum stress allowable in the various members is regulated by the load factor requirements of the specification. The term " load factor " requires some explanation, as it must not be confused with the term " factor of safety " which is used in ordinary engineering. Presuming that a bridge is built with a factor of safety of six, then it would be strong enough to withstand six times the maximum load that could

come upon it. If an aircraft is to be given a load factor of 8, then the aircraft structure has to be made capable of sustaining eight times the unit load imposed by the particular condition of flight being considered, not eight times the maximum load that can come upon it. The value of the load factor to be given to the various parts of an aircraft is difficult to fix, as the conditions of loading in special circumstances are extremely difficult to anticipate, but usually the requirements are that the components should be capable of withstanding a certain load factor under certain conditions, the factors required varying with the type and duty of the aircraft.

106. Service aircraft fall into various categories, such as high-speed fighters, reconnaissance or bombing aircraft, etc. The load factors required under the various usual conditions are given in the specifications for the types, and detailed loading conditions are given in " The Handbook of Strength Calculations," Air Publication 970.

107. The usual conditions for which calculations are made to determine the strength of an aircraft are the wing structure with the centre of pressure forward (C.P.F.) and centre of pressure back (C.P.B.), nose diving, landing, the cut wire case and inverted flight. The load factors for the wing structure are in the neighbourhood of 8 and 6, with the centre of pressure forward and back respectively. The term " centre of pressure " is explained in a previous chapter (para. 17). In a terminal nose dive, an aircraft is presumed to be dived at its maximum speed with engine off, and for this case the load factor is about $1\frac{1}{2}$. This condition frequently stresses the aircraft to a greater extent than any other condition for which the structure is investigated.

108. All Service aircraft are liable to have a flying wire shot away, or otherwise cut or broken. In these circumstances the rest of the wires and structural members are made strong enough to enable the aircraft to remain in the air and reach its destination safely. For this condition, called the " cut wire case," load factors of half the normal flight load factors are required. For inverted flight, load factors are required equal to 2/3 the centre of pressure forward factor on the wings.

109. The alighting gear of an aircraft is arranged to withstand an impact load caused by a vertical velocity of from 10 to 12 ft. a second, and under this condition the load factors on the undercarriage are about $1\frac{1}{3}$, and about $1\frac{1}{2}$ on the remainder of the structure. When the aircraft is at rest on the ground, the corresponding factors are 4 and $4\frac{1}{2}$. In addition, presuming that an aircraft is landing with a

considerable amount of drift, there will be a side load on the undercarriage ; this condition is allowed for by making the undercarriage, with both or all the wheels touching, capable of withstanding a side load equal to the total weight of the aircraft.

Strength of members.

110. The most important of the aircraft parts are either beams, struts or ties, as instanced by the spars, interplane struts and the bracing wires respectively. The theoretical strength of a member in tension, such as a bracing wire, can be obtained fairly simply by multiplying its cross-sectional area by the ultimate strength of the material used, and if the normal direct stress, as described in para. 100, is known, then the load factors may be obtained by dividing the ultimate strength by the normal stress. On the other hand, the theories governing the strength of beams and struts are rather complicated, and cannot here be gone into in any detail. (Those interested are referred to Air Publication 970 and other publications where these matters are treated at length). It is, however, possible to describe briefly the considerations which govern their use.

Spars.

111. Aircraft spars are beams with, in many cases, a fairly heavy end load. The stresses in the spars, or in any member subjected to bending, are of a very complex nature. Firstly, there is the direct transverse shear due to the load applied, and secondly there are the stresses produced by pure bending. The transverse shear in a spar or beam is directly proportional to the load applied, but the stresses due to bending require some explanation. In fig. 17, A is an unloaded beam, and B the same beam with a heavy load at the centre,

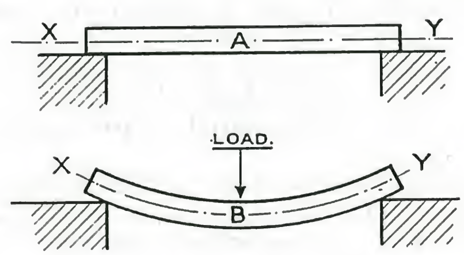

Fig. 17.—Loaded and unloaded beam.

the deflection being greatly exaggerated. Clearly, the upper surface of the beam B is shorter than the upper surface of

beam A, and the lower surface of beam B correspondingly longer than that of beam A. It therefore follows that at some plane in beam B approximating to X–Y the length is the same as that of the length of the same plane of the unloaded beam, or alternatively the same length as it was before bending. This plane is called the neutral axis. As indicated in the stress distribution diagram in fig. 18, all the fibres composing the beam above the neutral axis are subjected to compression and longitudinal shear stresses, and all the fibres below to tension and longitudinal shear. The longitudinal shear stresses are present as the result of the upper and lower fibres having expanded or contracted to a greater extent than the centre fibres, and although the section of the beam is homogeneous, there is some tendency towards relative movement between each minute layer of material. The tendency of each layer of the material to slide over its neighbour is resisted by the cohesion of the material itself. Bending a pack of cards illustrates what would happen if each layer were free to slide. Theoretically no direct stress due to bending is present at the neutral axis, but there are usually shear stresses, as explained

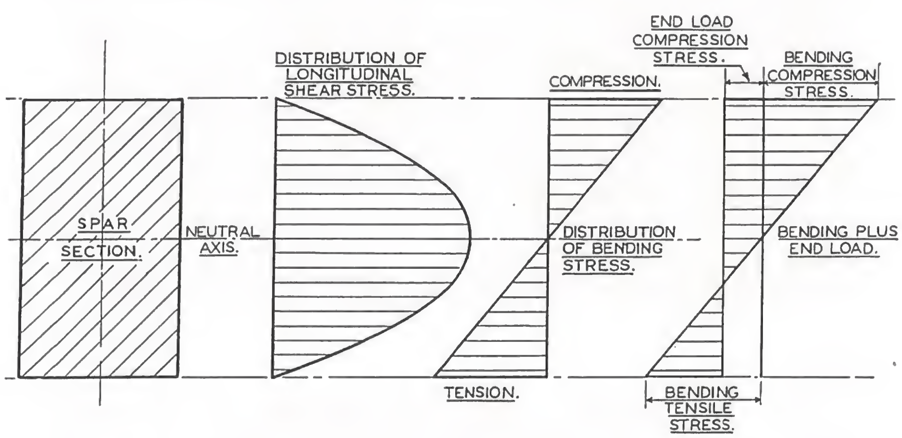

FIG. 18.—Diagram of stress distribution in a spar.

above, and these are at a maximum at this point. The stress distribution in a spar under bending, and bending plus end loads is indicated in the diagram given in fig. 18. A beam may obviously be of any cross-section, but the most efficient type is that in which most of the material is disposed as near as possible to the outer fibres, where the most work is done in resisting bending. The left-hand illustration of fig. 19 shows a section of the type of built up beam used in heavy engineering, the remainder show typical sections of beams or spars as used in aircraft.

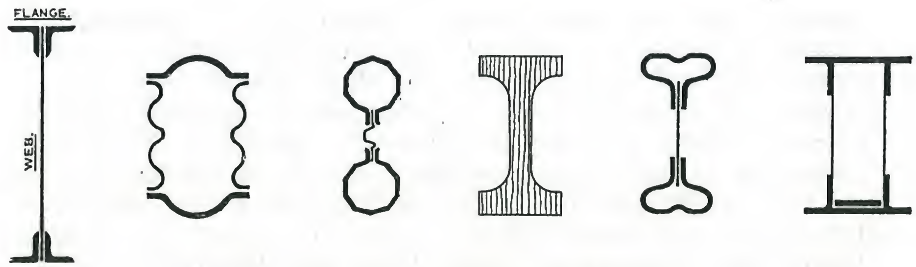

FIG. 19.—Typical beam sections.

112. In many cases an aircraft spar is subjected to end loads as well as bending loads, and is therefore acting partly as a strut and partly as a beam. When a solid member of regular cross-section, such as a wooden spar, is tested to destruction under these conditions, the failure can be usually attributed to primary causes, that is, owing to the externally applied load, some part of the outer fibres of the spar material reaches its limit of strength and failure occurs. On the other hand, when a hollow metal spar of built-up section is similarly tested, the failure may happen as the result of secondary as well as primary causes. Another, and perhaps more frequent, cause of failure of a spar under test is that due to instability of the section. Instability failures occur in those members where, in a effort to obtain the highest and most rigid form of structure, very thin materials are used, so that, when a relatively heavy load is applied, some portion of the section crumples up or collapses owing to lack of support. In actual flight it is a very rare occurrence for a spar to fail through the air loads alone, as very thorough strength calculations and tests are made to ensure that the spars are to the required strength.

Struts.

113. The strength of the strut depends upon its length compared with its cross-section, and also upon whether the ends are fixed or pinned. A fixed-ended strut is theoretically four times stronger than a corresponding pin-jointed strut, but full advantage cannot be taken of this for aircraft work, because parts to which the struts are connected are themselves comparatively flexible. In these conditions the benefit of using fixed-ended struts is doubtful, as it is possible for a strut of this nature to impart loads to the adjoining structure which would more or less nullify the benefit of the fixation of the strut ends. Take as an instance a fuselage strut which is connected to the longerons by rigid joints. Imagine that the strut has deflected under load, say from the undercarriage. The joint itself will not yield appreciably, so the longeron bends as well as the strut. If at the same time the longeron is

also highly stressed owing to, say, tail skid loads, then it is possible that the longeron would fail as the result of the combined loads, although quite strong enough in itself to withstand its own primary loads.

114. A strut, unless it is very short, cannot be subjected to the maximum compressive value of the material from which it is made, because when loaded at the ends a strut of parallel section will fail at the centre by bending as indicated on fig. 20. When a strut fails under end load, the stresses in the

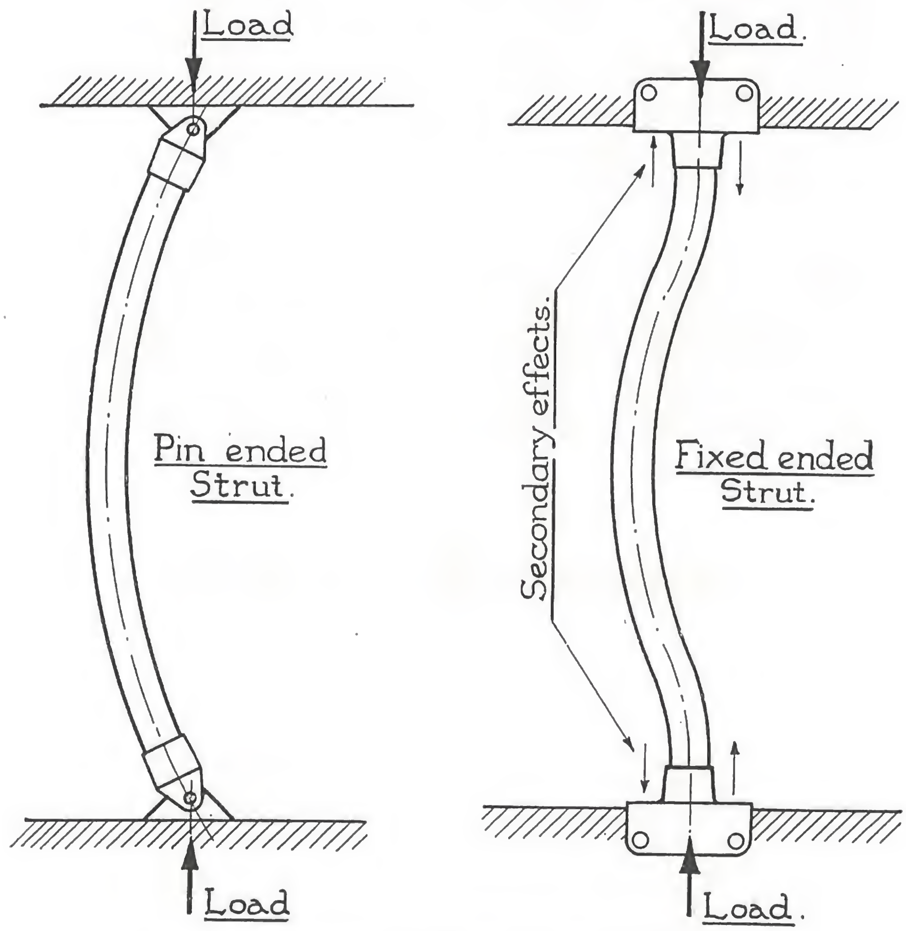

FIG. 20.—Loaded pin ended and fixed ended struts.

material are partly attributable to the direct end load applied and partly to the bending action. The stresses due to the bending action are practically identical to those in a beam under bending loads, which have been already described.

115. When a loaded strut of any form is damaged by having a dent made near the centre of its length, the stresses in the material may be very much increased. If we take a tubular steel strut and apply a safe load to its ends, the stresses are fairly even over any section taken through the strut, because the material is of even thickness, and each small section or part of the section is deriving an equal amount of support from the remainder. When a dent is made, it is clear that this support is taken away or much changed over the portion distorted by the dent. The result is that the undistorted portion is taking more than its share of the load, and is therefore unevenly and more highly stressed. This is more easily understood if para. 103 is read, and the dent is considered as a hole. It is therefore obvious that a dent which is short, but which extends a considerable distance round the diameter of the tube, is more dangerous than a narrow depression running some way along the length of the strut.

116. All pin-jointed struts of parallel section are most liable to failure at mid-length; therefore, whenever it can with advantage be done, struts are thickened up at the centre and tapered off towards each end. In some cases, though very seldom in aircraft construction, where the strut is of abnormal length it is braced by struts and wires as shown in fig. 21. This method effectively halves the length of the strut. The

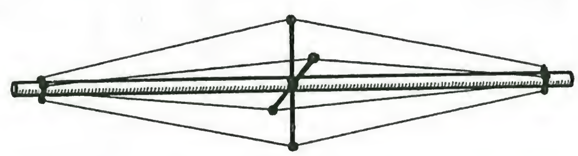

FIG. 21.—Braced strut.

same effect is obtained if an attachment is made from a more secure portion of the structure to the centre of the strut. Some preliminary indication of the failing strength of aircraft struts is frequently given by visible bowing under load, so that it is clear that struts should not be loaded transversely or have any initial set or bend unless originally designed in this manner, since this condition increases the bending moment due to the end load.

In the larger size of struts, a considerable economy of weight of material can usually be made by employing a built-up type. This type is especially applicable to heavily loaded interplane struts of streamline section.

Fittings.

117. Most well designed fittings have the lines of action of all the loads coming upon them meeting at a point. In other words, if an imaginary line is drawn through the centre of the struts, wiring lugs and other load-carrying parts attached to the fitting and produced through to the centre line of the main member, all the centre lines will meet at a point on the centre line of the main member, as shown in fig. 22A any departure from this imposes an off-set load, and therefore a bending moment, on the main member.

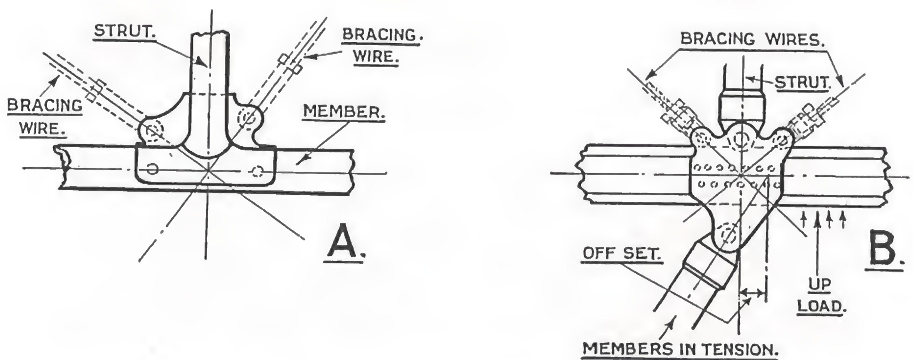

FIG. 22.—Lines of action in fittings.

118. It is not always possible to avoid off-setting a wiring lug or similar attachment, especially in the case of hollow metal spars. In these cases the members affected have to be made sufficiently strong to withstand the bending loads caused by the off-setting. There are also instances where a deliberate off-setting has been arranged for one of the attachments of a fitting, in the manner shown on fig. 22B, so that the bending action caused thereby tends to cancel out a bending load in the opposite direction which is caused by some other action.

119. All fittings are to some extent subjected to vibrational loads, but the durability of those fittings which take the direct vibration from the engine, such as those on the engine mounting, cannot be judged by the ordinary strength calculations. Unless the areas in contact are of ample size, the hammering action produced by the partial or complete reversal of load caused by the vibration will, in time, cause elongation of holes, or fatigue cracks (as explained in paras. 97 to 99), and finally failure.

Bolts used on the principal fittings are always arranged to be either in tension or shear, or a combination of both, and pins in shear only. These parts are never subjected to bending if it is at all possible to avoid it, as the stresses in the

part would thereby be very much increased. This points to the necessity of keeping all bolts or pins drawn up tight. Whenever it can be arranged, bolts and pins are placed in double shear as indicated on fig. 23.

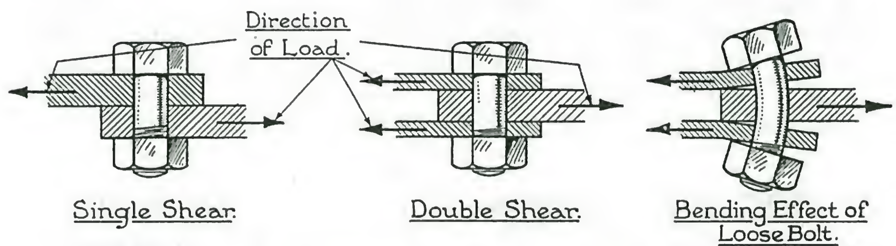

FIG. 23.—Single and double shear.

120. Riveted joints of any form are always arranged so that the loads which they carry place the rivets in direct shear. The kinds of rivets employed are illustrated in fig. 95 and described in para. 388, and the usual types of riveted joints are shown in fig. 96. Plate fittings are made where possible from a single thickness of plate which, if necessary,

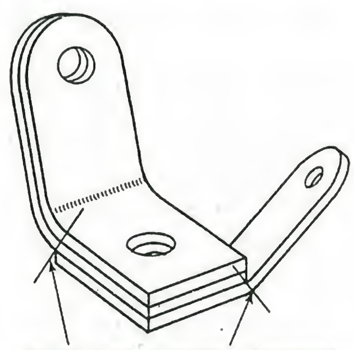

FIG. 24.—Laminated plate fitting.

may be machined down in places to any required thickness. Laminated plate fittings of the type shown on fig. 24 are seldom used, as they are apt to give trouble at the junction of the plates, especially if the parts are highly stressed and there is a large difference in the thickness of material at the change of section. Wiring lugs which are at an angle from the main fittings are usually arranged with the bend close up to the holding-down bolt, as indicated in fig. 25A, but when this is not possible a block or pad is sometimes arranged under the head of the nearest bolt, as shown on fig. 25B, to prevent

any distortion. Wiring and other lugs are always bent to the same angle as the wires or struts to which they are attached.

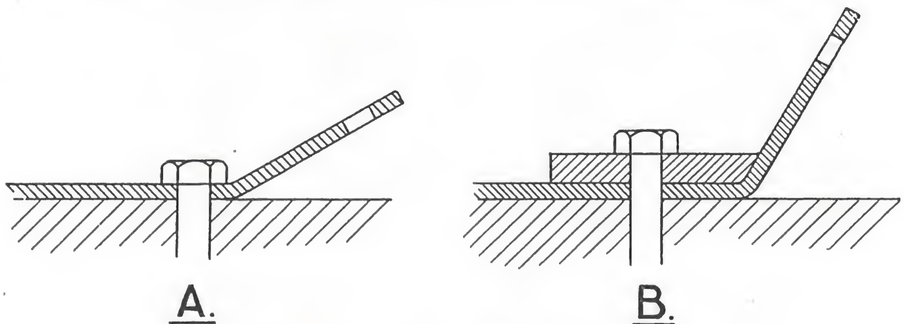

FIG. 25.—Wiring lug attachment.

Braced Structures.

121. Bracing is used in any structure, and particularly so for aircraft, to obtain rigidity with the least possible expenditure of material. Most aircraft parts would need to be a great deal heavier if bracing in one form or another was not employed. In their usual form, aircraft structures consist of open frames built up from struts and ties, pin-jointed together, and designed to be loaded mainly at the joints. A perfect frame has neither too many nor too few members. Fig. 26A represents a perfect frame in its simplest form. If a structure of this type is supported at A and C, and a load applied at B in the direction indicated by the arrow, then this load will be resisted by pure compression and tension in the members A, B, and B, C. Fig. 26B shows a frame which is imperfect, because it would deform if a load were applied

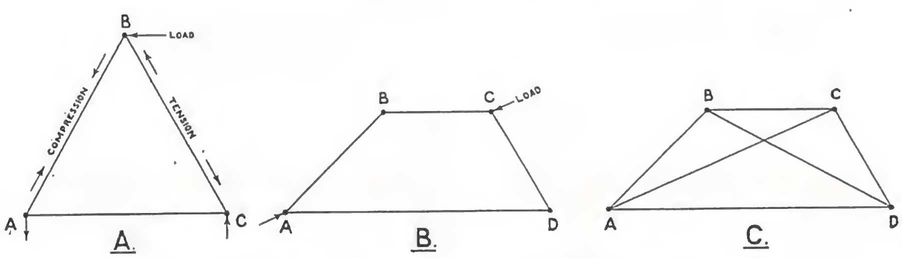

FIG. 26.—Perfect and imperfect frames.

in the direction A to C, although it would be in equilibrium under certain conditions of loading. The number of members required for a perfect frame can be determined by the formula $2n—3$ for flat frames, and $3n—6$ for " solid " or cubical frames, where n equals the number of nodes or joints. Taking the frame as given at B, fig. 26, the number of joints is four,

therefore $(2 \times 4) - 3 = 5$, so that in this instance it would be necessary to have a diagonal strut in addition to the side members. A diagonal bracing strut in a flat four-sided frame can always be replaced by cross bracing wires if desired, as shown at C, fig. 26. If both the wires were replaced by struts then the frame would be "redundant" on account of the fact that there would be one member too many. It is not only necessary to have the correct number of members and joints, but it is essential that they should be correctly arranged with respect to one another.

122. Bracing for aircraft fuselages takes, broadly speaking, three forms, diagonal wires, struts and panels. When wires are used, say, to brace a fuselage bay, these are taken diagonally across from corner to corner, and when the fuselage is under load, one or the other of the wires is in tension, depending upon the direction in which the load is applied, as indicated in fig. 27A. When strut bracing is employed, as at fig. 27C and D, single diagonal struts replace

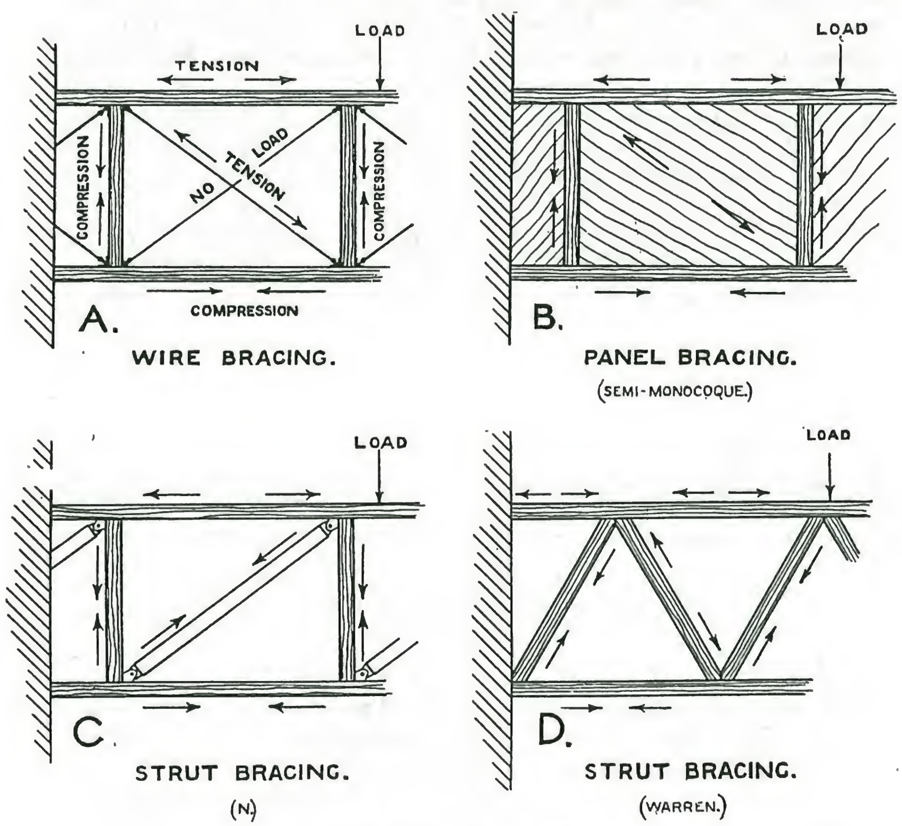

FIG. 27.—Braced frames.

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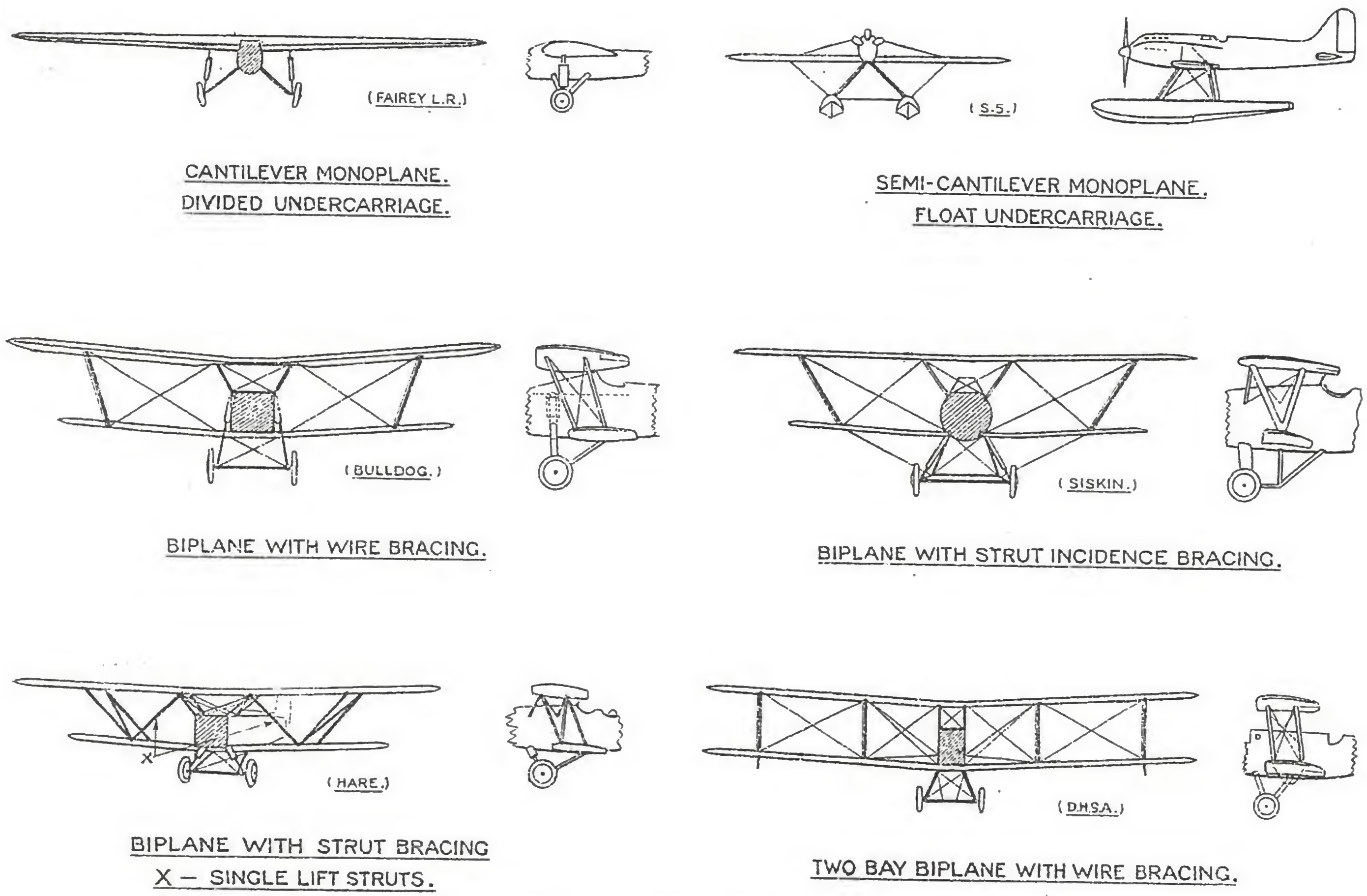

FIG. 28. TYPICAL FORMS OF BRACING.

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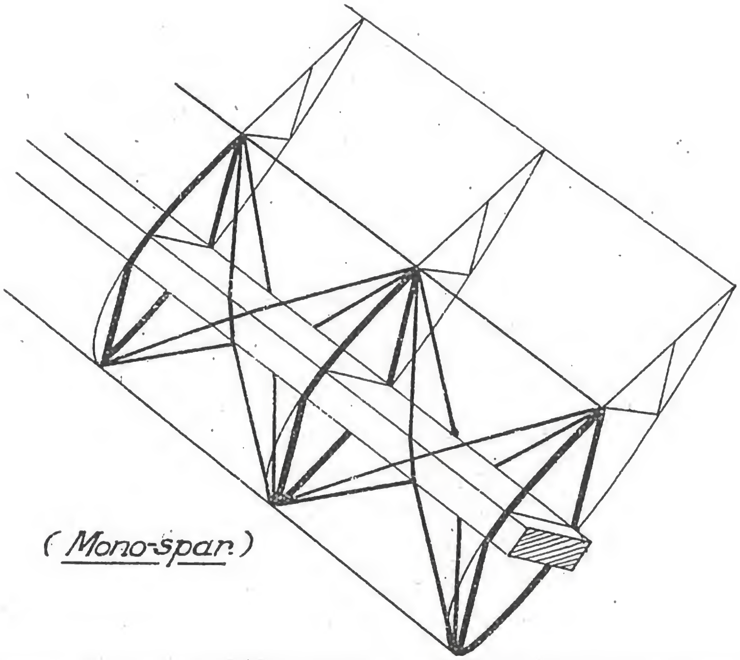
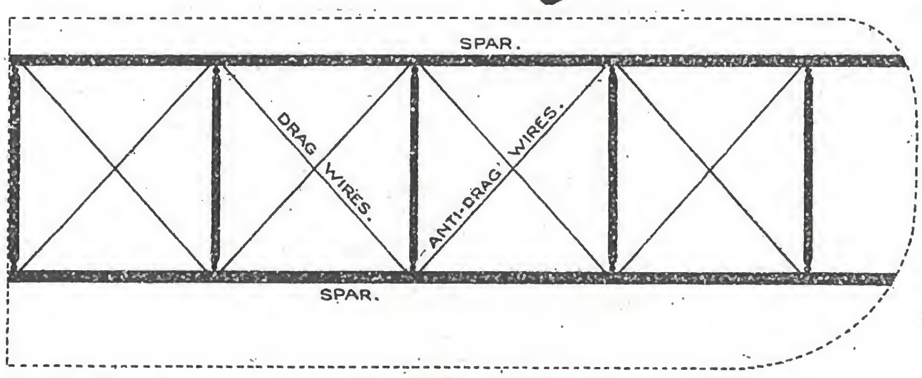
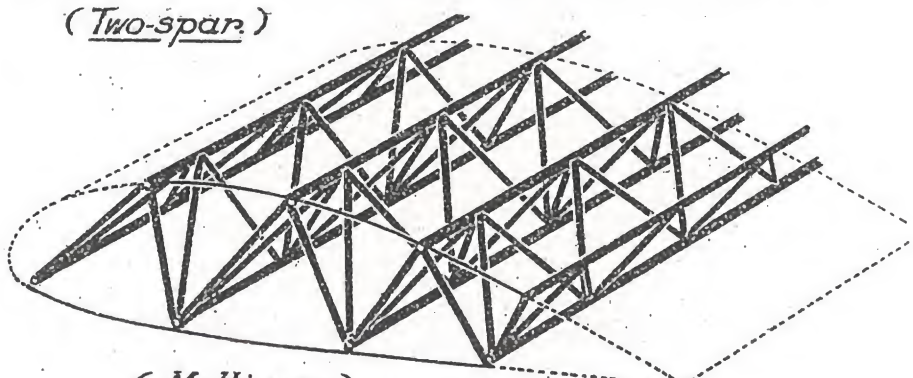


(*Mono-spar*)



(*Two-spar*)



(*Multi-spar*)

FIG. 29. TYPES OF INTERNAL WING BRACING.

the wires, and when under load, are either in tension or compression, also depending upon how the load is applied. Three-ply (or possibly sheet metal) panels sometimes replace wires or strut bracing in aircraft structures as illustrated at B, fig. 27. The loads in panel bracing are mainly taken in tension, but the stresses are of a complex nature owing to the com-ression buckling and shear stresses. This type of panel is very effective in maintaining the shape of the structure.

123. Details and materials may vary considerably, but the plan arrangement of any biplane wing generally follows well established economical lines, such as that shown in the centre illustration of fig. 29. It consists of an open frame composed of two spars, drag struts, drag and anti-drag wires. To this frame are attached ribs which are shaped to form the desired wing section and made strong enough to take the air loads imparted by the fabric, with which the whole is covered. Monoplane wings, on the other hand, may vary considerably in general design, especially in the case of the cantilever monoplane, but for the smaller aircraft of this type the same two-spar construction is generally used. On the larger monoplanes there may be one, two or a number of spars and the covering may be of fabric, wood or one of the light alloys. The wings of a cantilever monoplane are thicker than the wings of a biplane of similar weight, chiefly owing to the practical necessity of having to provide a greater depth of section for the internal structure. The greater depth of section is also required to allow adequate precautions to be taken to resist the twisting imposed by the ailerons, which on the larger monoplanes is a serious consideration. When a stronger substance than fabric is used for the plane covering, it is generally used as a strength member, and definitely takes a proportion of the air loads. This does not refer to the solid coverings used as walkways or engine platforms. Fig. 29 shows types of internal bracing used on mono-spar, two-spar and multi-spar wings. In the multi-spar diagram shown, the covering would have to take a large percentage of the loads.

124. When cellule or six-sided cubical bracing is considered, such as is usual in the wings of biplanes, it is not essential for complete rigidity that all six sides should be braced. Provided that the base is rigidly supported, it is only necessary that four other sides should be braced, as shown on fig. 30. As indicated, any side loads imparted to the members of the open end are resisted by the struts and diagonal bracing of the sides. If the base is not rigidly supported, then the structure will be flexible, owing to distortion of the members constituting the base, in a direction at right angles to the plane of that base.

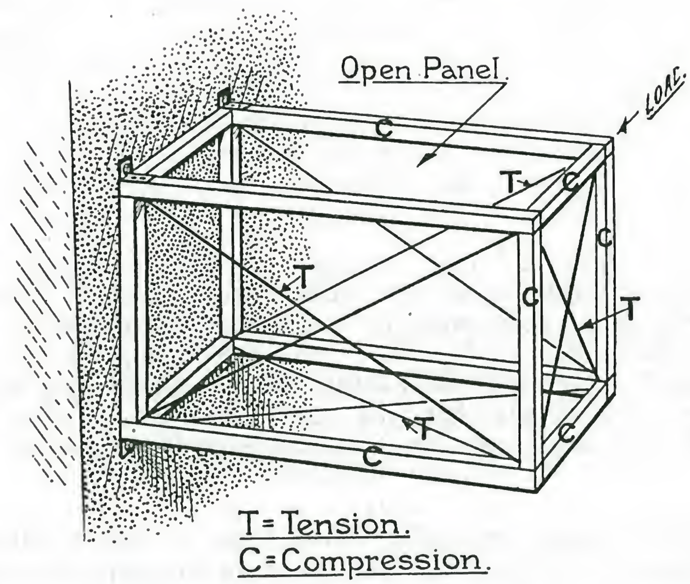


FIG. 30.—Cellule bracing.

125. In order to differentiate between the wires used for bracing aeroplanes, they are generally indicated in terms of the purpose for which they are used. In this way, as indicated in fig. 4, the " Lift " wires are so called because the principal function of these wires is to transfer the lift of the wings to the body or other part of the aeroplane, the " anti-lift " or " landing " wires resist forces in the opposite direction to the " lift " wires, and are usually under maximum load only during landing. " Drag " wires are those which transfer the drag of the planes to the body or other part of the structure, " anti-drag " wires resist forces in the opposite direction to the drag wires, and the " incidence " wires brace a main plane cellule in the plane of a pair of interplane struts. Some of the various forms of wing bracing in common use are shown in fig. 28; all the types illustrated being tractor aeroplanes.

126. An undercarriage bracing is usually similar in principle to one of the types of bracing described in paras. 246 to 248, and generally takes the form of cross bracing wires or cables, but the kind of bracing depends largely upon the type of undercarriage employed, many modern undercarriages being strut-braced. Undercarriage bracings and structure are sometimes slightly complicated by having universal joints at the ends of the articulated struts or radius rods. These joints are necessary in order to permit the movements required for the shock absorbers. The types of undercarriage can be

classified as through axle, divided axle, twin, and float, all of which are shown diagrammatically in fig. 28.

Shock absorbers.

127. Before an aeroplane can come to rest, during the operation of landing, the forward velocity must be absorbed in the work done in travelling over the ground, but the downward velocity must be absorbed in the structure itself; therefore, some form of shock absorber is necessary.

128. In all properly designed shock absorbers, the principle is very similar, and that is to convert the kind of energy possessed by the aeroplane when landing, called kinetic, into some other form which can be easily dissipated. Shock absorbers take the form of steel springs, rubber in tension or compression, or some type of oil or air dashpot. Steel springs, or rubber in tension, operate by storing up the energy imparted to them during landing, and retaining the energy until released. Oleo shock absorbers convert the kinetic energy into heat by the work done in the dashpot, and give off the heat by conduction and radiation. The functioning of the compression rubber shock absorbers is a combination of the principles of the spring and the oleo, most of the energy being stored, and the remainder dissipated as heat. Figs. 47, 67, 68, 69 and 70, show the various types of shock absorbers used.

CHAPTER V.

WOOD AND COMPOSITE CONSTRUCTION.

General.

129. In modern designs of aircraft for service use, wood is seldom employed for the main members, its use being confined to subsidiary structure and fairings. There are perhaps two main reasons for this, and they are, firstly, that the kind of timber used is not grown in England in sufficient quantities to provide adequate supplies, and has therefore to be imported. This would prove to be a serious handicap in any national emergency in which a large number of aircraft were required immediately. Secondly, wooden aircraft structures are very much affected by extremes of atmospheric conditions and are therefore expensive to maintain in tropical or sub-tropical countries.

130. It is, however, doubtful if under normal conditions, wood will be entirely eliminated in the construction of aircraft of all types; therefore, a short description of the more usual forms of construction is given.

Wooden construction.

131. In comparison with all-metal aircraft, the wooden type is undoubtedly cheaper to produce in any but very large quantities, not so much on account of the cost of materials, as of labour and the plant required for manufacture. Also wooden aircraft structures are generally slightly lighter than the corresponding metal type, though this greatly depends upon the size and type of the aircraft. In the light plane class, say up to 2,000 lb., wood has a distinct advantage over metal on the score of weight, but in the medium weight range, although wooden aircraft are usually lighter than metal aircraft of the same type, it is much a matter of the duties of the aircraft and the care with which the metal aircraft has been designed. In the larger aircraft, all-metal construction is generally considered to be superior to wood as regards weight. Wooden aircraft structures can absorb vibrations and minor shocks without material damage to a greater extent than can metal, but under large shock loads, say in the event of a crash, wood is more apt to splinter and totally collapse. Repairs are made comparatively easily to wooden structures, and as a rule do not require the skill generally necessary for repairing metal parts.

Composite construction.

132. Composite aircraft are those aircraft which have some of the main members formed of wood and some of metal.

This type of construction has the advantage that the material best suited to the individual parts can be used. Composite aircraft may have metal spars with wooden ribs or completely wooden wings, but with the fuselage made wholly, or partly of metal. Many modern aircraft are built in this way, as this type of construction usually provides a very rigid structure with a long life. The cost of production varies in accordance with the number and type of metal parts employed, but, if economy has been observed, the cost in labour and materials is little more than that of wood, and the weight should not greatly exceed that of a corresponding wooden structure.

Timber.

133. All timber for use in aircraft construction is very carefully selected and stored, but even so a considerable wastage occurs, due to the many diseases and defects such as shakes, checks, knots, gum pockets, seasoning cracks, dote, spiral grain, and so on.

134. On account of its light weight, straight grain, strength and easy working, spruce is the most widely used form of timber for aircraft use. Other woods are used, such as mahogany, ash, and cedar, but owing to their weight these kinds are normally only used for airscrews and packing blocks and other parts of the aircraft where special hardness or strength is required. Ply wood is used extensively for fairings and other parts, and is valued on account of its strength, pliability and general adaptability for aircraft purposes, but is comparatively heavy.

135. Wooden aircraft components very quickly deteriorate if they are subjected to extremes of humidity or dryness of the atmosphere. The glued joints are the first to suffer if it is too damp, and timber shrinkage occurs if the conditions are too dry. Timber shrinkage causes disruption of the glued joints, and slackness of all metal fittings.

136. Constant periodic inspection is necessary during the storage of wooden airframes or aircraft components, and as far as possible a constant temperature of between 50° and 60° F. is to be maintained in the storage sheds, if the parts are to be properly preserved.

Glued joints.

137. Glued joints play a great part in the construction of wooden aircraft, and the condition of the glued joints is some measure of the serviceability of the aircraft. For this reason special measures are taken with the glued joints of any main member, to assist as far as is possible in the maintenance of the joints under any conditions of service. The usual

method adopted is to cover the joint with a strip of tape, which is glued and then well varnished. Great care has to be taken when making glued joints to ensure that the glue is acting as an efficient fixative, and the precautions to be taken vary with the type of glue used. Cold glues are in more general use than hot glues, and these have to be applied in the manner stated in the specification for the particular kind of glue. A glued joint properly made, between two pieces of light timber, can be as strong as the timber itself. This does not apply to joints made on the end grains, or between pieces of hard or close-grained timber. Joints made with cold glue are not quite so strong in the first instance as those made with ordinary glue, but as cold glues are generally considered to be more waterproof, the joints made with these substances would probably be in better condition after some period of service.

138. The supply of straight-grained timber in lengths suitable for members such as longerons, is strictly limited. Therefore, two shorter pieces of timber are sometimes spliced together to make up the length required. On all members subject to bending, the splice is placed at the point of contra-flexure, or that portion of the member where the least bending occurs. Struts are very rarely spliced. The length of the

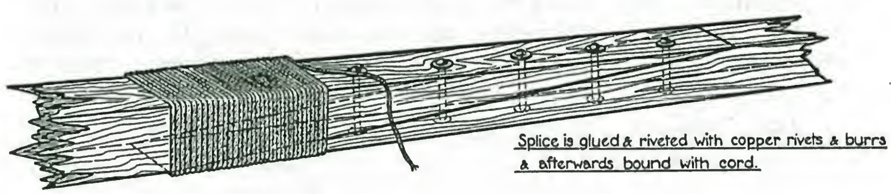


FIG. 31.—Splice in wooden member.

tapered portion of the member forming the splice is never less than nine times the width of the member at the join. Fig. 31 shows a typical splice in a longeron. It will be noted that rivets and binding cord are used in addition to glue. The additional precautions are not required for strength alone, but are provided to prevent, as far as possible, any deterioration of the glued joints under adverse conditions.

Wooden planes.

139. In their general aspect, that is, considering the actual structural design as apart from the materials used, there is a marked similarity between the planes of all biplanes, and this is especially so with regard to wooden planes. Fig. 32 represents a typical example of a wooden plane with the fabric

stripped off. In this case, it will be noted that solid spindled, or I-section spars have been used, and also that certain of the

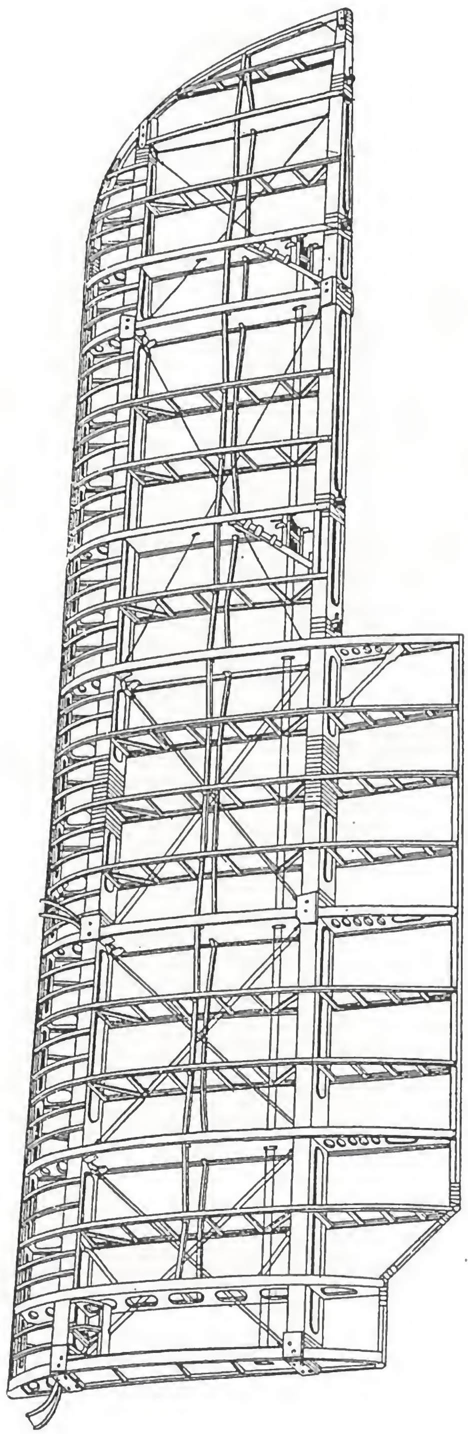


Fig. 32.—Typical wooden plane.

ribs are solid and act as the drag struts, instead of these parts forming a separate item as they often do. Also, that the three inner sections of cross bracing have been duplicated to comply with the "cut wire case," which is laid down as a necessary condition for service aircraft. The leading and trailing edges are made of spruce, and the ribs are attached to these parts and to the spars by gluing and bradding. Some typical interplane strut fittings are shown in fig. 33.

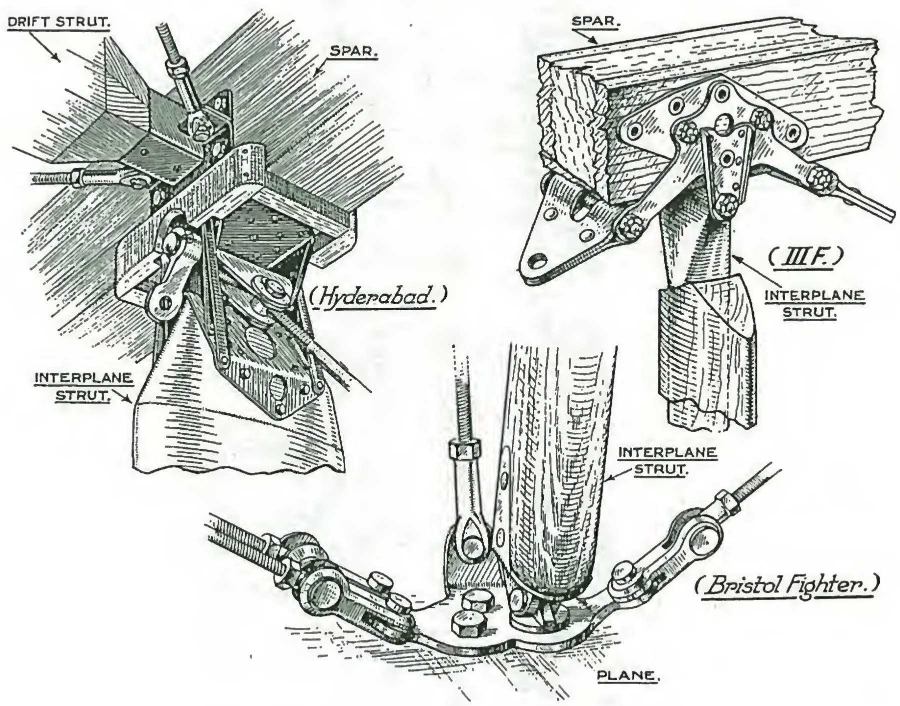


FIG. 33.—Wooden interplane strut fittings.

140. With the few exceptions of those aircraft which use the wing covering as a strength member, all aircraft planes are covered with fabric. Only the best quality of linen is used for service aircraft, and the manner in which this material is sewn to the ribs is very important, and must be done in certain specified ways which are described in a later chapter.

Composite planes.

141. Composite planes are constructed on similar lines to wooden planes, with the exception that usually the spars are of metal. The metal spars used on composite planes are in some instances made of tubular steel, but in most cases the spars are built up in much the same way as for all-metal planes, as described in a later chapter. A tubular spar is

generally made up from a single length of tube of the appropriate diameter and gauge, which is sleeved externally at the attachment points by sliding on short additional lengths of closely fitting tube.

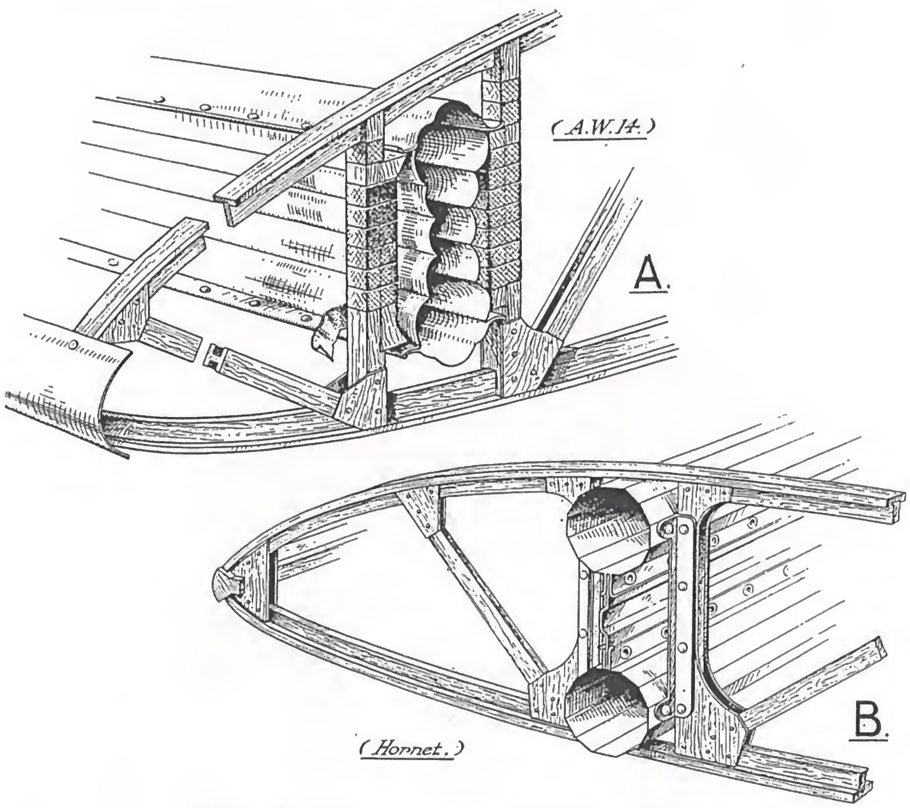


Fig. 34.—Composite plane rib attachments.

142. The wooden ribs are usually quite normal in design, and are sometimes attached to the spar with some form of metal clip such as that shown at B, fig. 34, and in other cases are arranged as indicated at A. Fig. 35 indicates a type of fitting employed when the outer wing spar is of wood, and the centre section of metal.

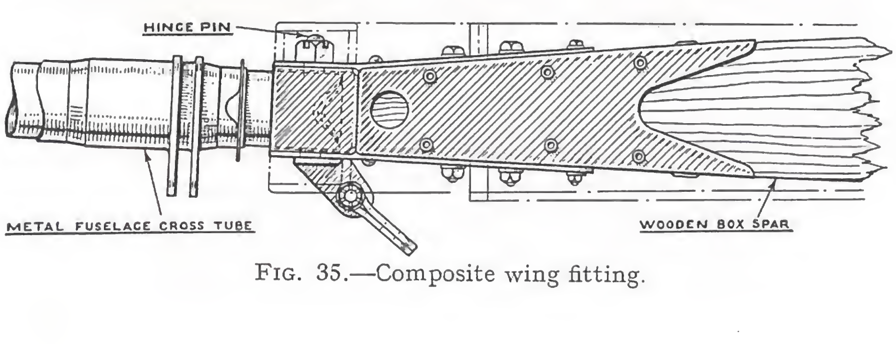


Fig. 35.—Composite wing fitting.

Wooden spars.

143. The most important of the main members of an aircraft are the spars, and the forms the wooden spars take are normally either solid, box or I-section, of which examples are given in fig. 36. In the manufacture of spars, and other main members, the greatest care has to be taken in the selection of the timber, because not only has the wood to be free from the many possible defects, but it has also to be free from any excessive spiral grain, no more than 1 in 10 or 12 being allowed. The spindled, or I-section spars are usually machined from the solid timber, but they can be made up from strips of wood glued together forming horizontal or vertical laminae.

144. In the built-up type of spar, such as the box, the flanges are almost invariably of spruce and the webs are either of this material or of three ply. The actual details of the design of the spar depend to some extent upon the individual taste of the designer, and also upon considerations of detail such as the depth available for the spar in the wing section, and the loads coming upon it. At all attachment points, wooden spars are usually increased in section, squared off and made solid as shown at the lower illustration in fig. 36. This is because in most cases the points of attachment are also the points of greatest

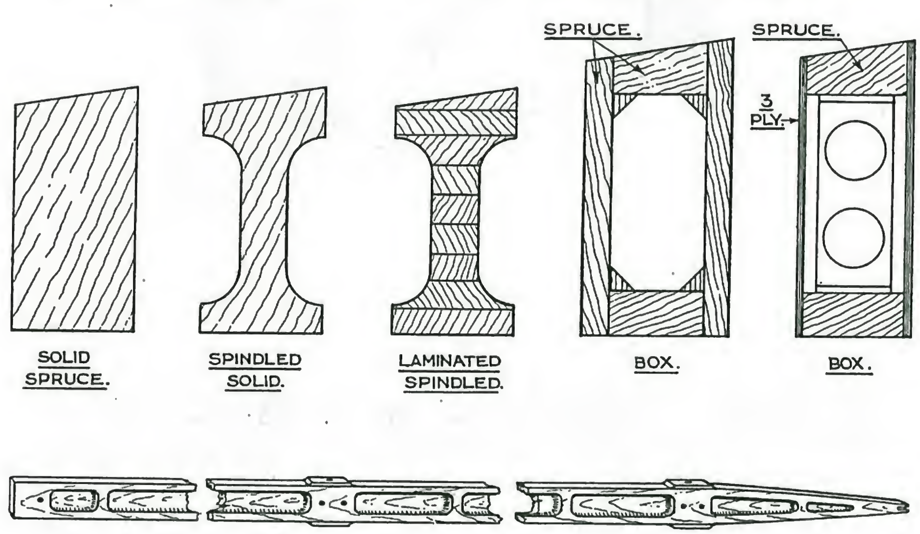


FIG. 36.—Wooden spar details.

concentration of loads in the spar, and the necessity of drilling the spars for the bolts attaching the fittings would unduly weaken the spar unless some additional material was provided. The squaring off is done more for convenience in design and erection than for any other reason, as a square face is more easy to work from than an inclined one. Hard wood packing

blocks, glued and screwed on, are usually employed at the fitting attachment points. Spruce packing blocks are occasionally used, if the area of contact between the metal fitting and the wood is sufficiently large to allow of it, but hard wood is preferable in all cases, as this kind of wood is less liable to crush or shrink in service.

145. The spars of biplanes are usually parallel in section but tapered off at the wing tip, but the shape of monoplane spars depends upon whether it is a pure or a semi-cantilever type. In pure cantilever wings the spars generally follow the wing thickness which most designers arrange to be tapered, having the greatest thickness at the centre, or wing root. Semi-cantilever spars may or may not vary in thickness of section, depending upon the shape of the wing and the reasons governing the designer's selection of the type of construction, such as economy in manufacture, efficiency in service and general appearance.

Wood and composite struts.

146. Wood struts for use on aircraft vary considerably in cross-section and other details of design, depending to a great extent upon whether they are used externally or internally. A few of the more usual types of hollow sections are given in fig. 37. For the sake of economy, struts are usually made

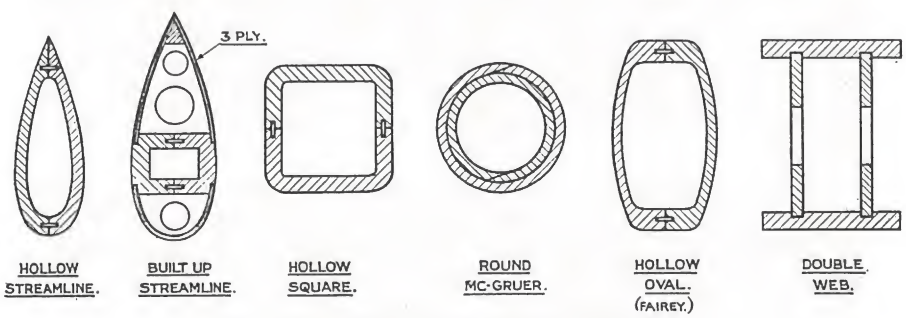


FIG. 37.—Hollow wood strut sections.

parallel in section, but they may have their ends tapering and can be either solid or hollow. In all cases it is usual to have some form of metal end fittings for the attachment of the struts to the adjoining structure. Interplane struts have normally a streamline section, and the end fittings form sockets which not only provide the bearing surface required for the pin joints, but also protect the ends of the wooden strut and guard against splitting or spreading as shown in fig. 33. Other forms of strut, such as are used in fuselages, are in many cases attached only by side plates with or without wooden corner chocks to position the ends, as indicated in fig. 41.

Composite struts are made of wood and metal, and some typical sections are shown in fig. 38.

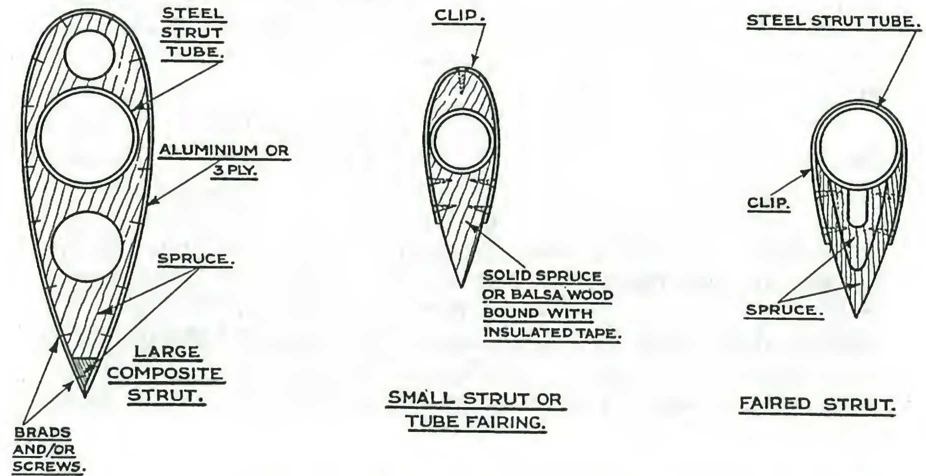


FIG. 38.—Composite strut sections.

Wooden ribs.

147. For the most part wood ribs are built up entirely from spruce, or are composed of a spruce flange and a three-ply web, a typical example of the former method being given in fig. 39. Special strong ribs are sometimes used which act as drag struts as shown in fig. 32. These ribs are usually strengthened by having a solid web, or if this is not sufficient, the webs are duplicated and so form a box-section rib. In all cases ribs are made as light as is compatible with their duties.

In wood aircraft the ribs are usually glued and bradded to the spars, and connected together at the front and back by leading and trailing edge strips, and also, at some point about midway between the spars, by stringers. In composite aircraft where a metal spar is used, the ribs are arranged

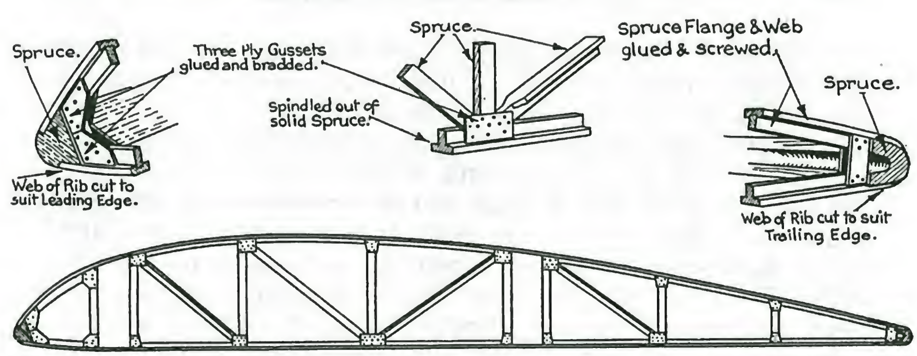


FIG. 39.—Typical deep section wooden rib.

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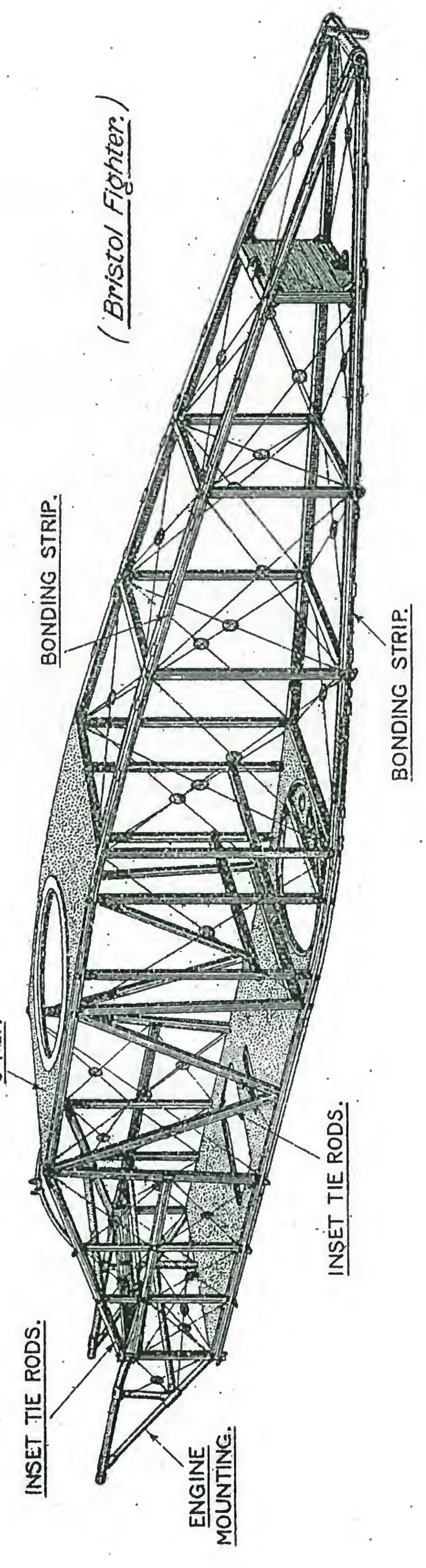

FIG. 40. WOODEN FUSELAGE.

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very similarly except that a different form of attachment to the spar is used, as already described in para. 142.

148. Before any design of rib is approved for use in service aircraft, two or more specimens are tested to destruction with a distributed load for the two extreme conditions of flight usually encountered in aircraft fitted with wings of normal section, that is, with the centre of pressure right forward, and right aft.

Wooden fuselage construction.

149. A normal type of wood fuselage is shown in fig. 40 ; in this case the wooden longerons are separated by wood struts and braced diagonally by swaged rods. Metal fittings, disposed at the junctions of the struts and longerons, serve as a means of attachment, and fig. 41 shows some typical fittings. The longerons are usually rectangular in section, spindled out between the struts to obtain as light a structure as is compatible with strength. Longerons may be composed

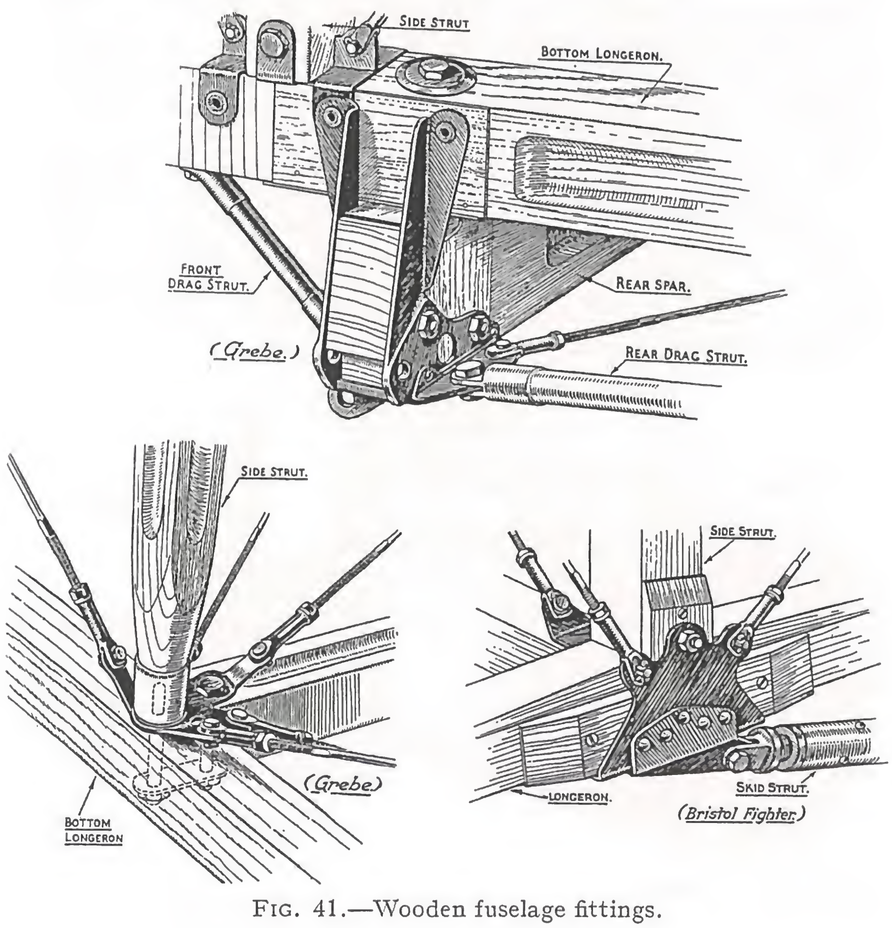

FIG. 41.—Wooden fuselage fittings.

of one length of timber or two, and in the latter case may be spliced or connected together by metal fittings.

150. In some instances, wood fuselages are built with single struts or three-ply panels in place of the cross bracing wires. The strut form of bracing is seldom used throughout the fuselage, but is generally only employed in those bays where the type of loading or some other special considerations makes it necessary, as fixed struts preclude any of the rigging adjustments usually required for wooden aircraft structures. With the three-ply panel, or semi-monocoque, type of construction, the three-ply usually replaces the diagonal wires only in the longitudinal bays, and is a comparatively heavy form of structure as its reinforcement by struts is still necessary, especially where any form of compression load comes upon the three-ply.

151. The true wood monocoque, shown on fig. 42, is a type of construction which is different in principle from the usual form of fuselage. In this case the skin is used to take the loads imparted by the tail, the shape being maintained by formers and stringers. Additional members are used to transfer the heaviest loads through the fuselage or provide means of attachment. The skin may be a double layer of spiral timbers as shown, or may be a single layer of three-ply or similar material. It is usual to have an outside covering of fabric which is glued on and doped or varnished. This type of construction is now seldom used except for special purposes, such as seaplane hulls or the fuselages of racing aircraft, as, although it is very strong and light, it is expensive to manufacture and repair.

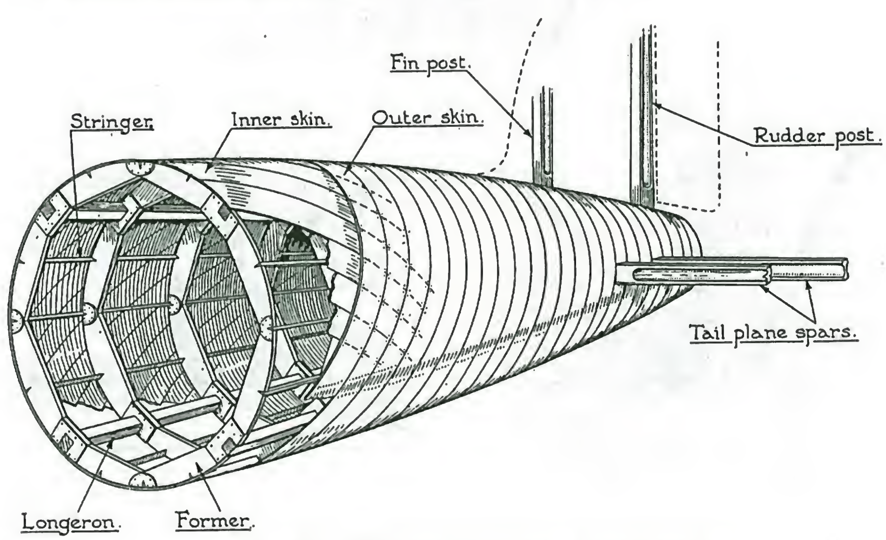

Fig. 42.—Wooden monocoque construction.

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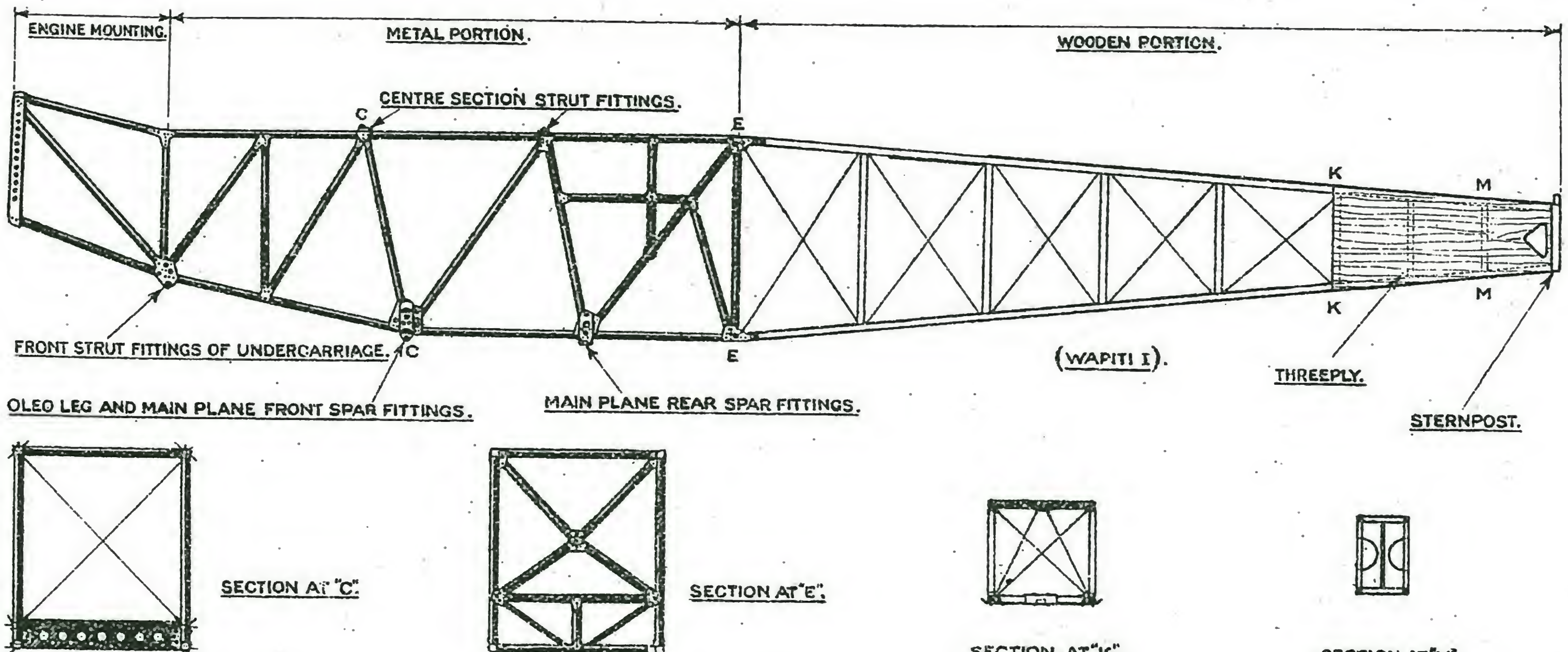

FIG. 43. COMPOSITE FUSELAGE.

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Composite fuselage construction.

152. Composite fuselages take a variety of forms, but the usual compromise is that in which the front end of the fuselage is of metal whilst the rear portion is of wood. Fig. 43 shows a typical composite fuselage of this kind. The fittings used on the wood and the metal portions must obviously be made suitable for the particular type of construction employed, the only difference in the type of fittings used being at the junction between the wood and the metal. Fig. 44 gives a few fittings of this nature.

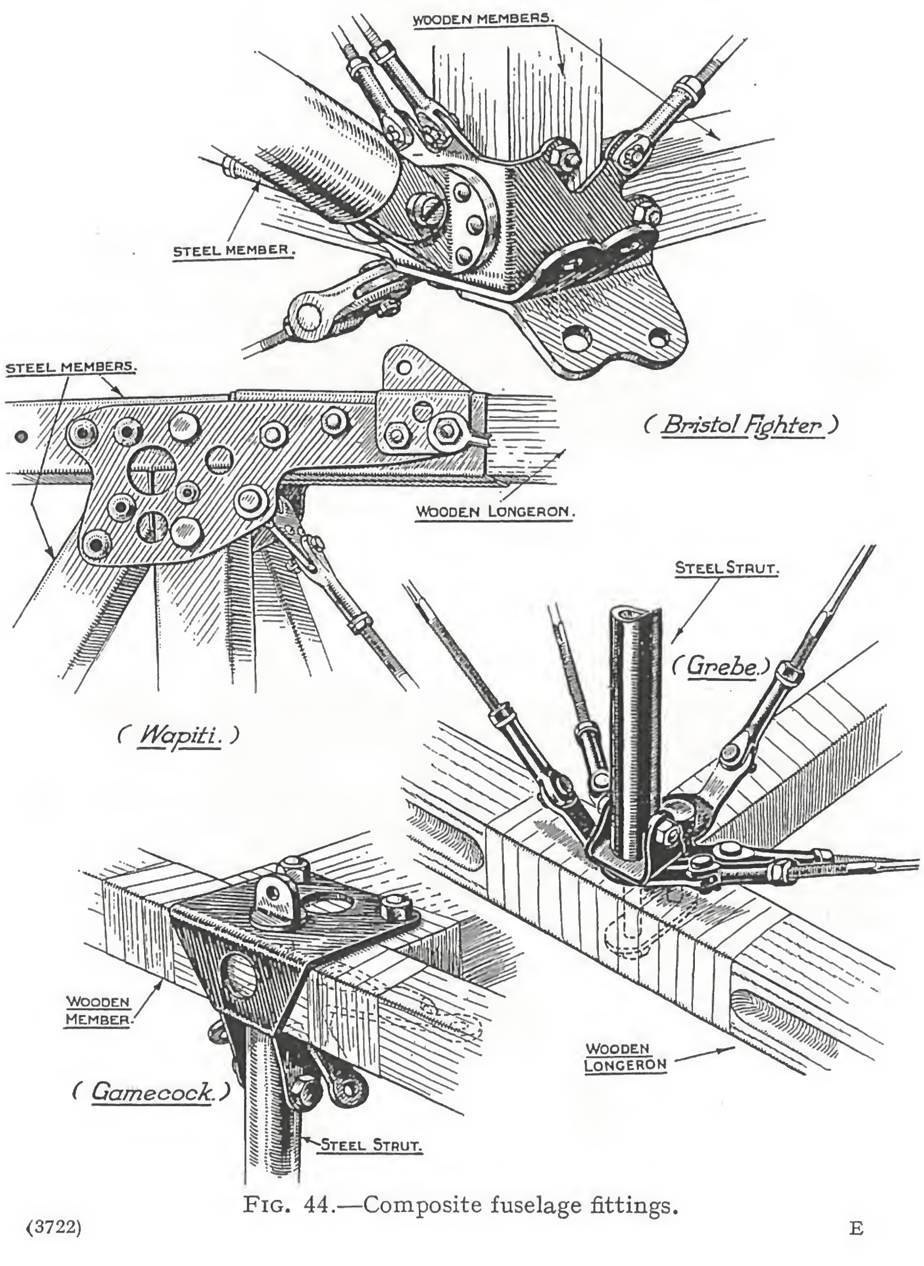


FIG. 44.—Composite fuselage fittings.

Wooden fuselage fairings.

153. In most types of construction, the shape of the fuselage, as observed on a complete aeroplane, is seldom the shape of the actual fuselage frame, but is a structure superimposed on the main fuselage frame in order to fair off and give the body a streamline shape. In the majority of cases the body form is enlarged at the top at the cockpit positions, in order to give greater accommodation than is usually provided by the fuselage frame itself. The enlargement is achieved, generally, by building up a strong three-ply superstructure on formers, which is then bolted to, or otherwise secured to the longerons, and covered with doped fabric. The fairing surrounding the engine mounting is normally made of aluminium, and is so arranged as to be easily and quickly detachable, thereby giving ready access to the engine

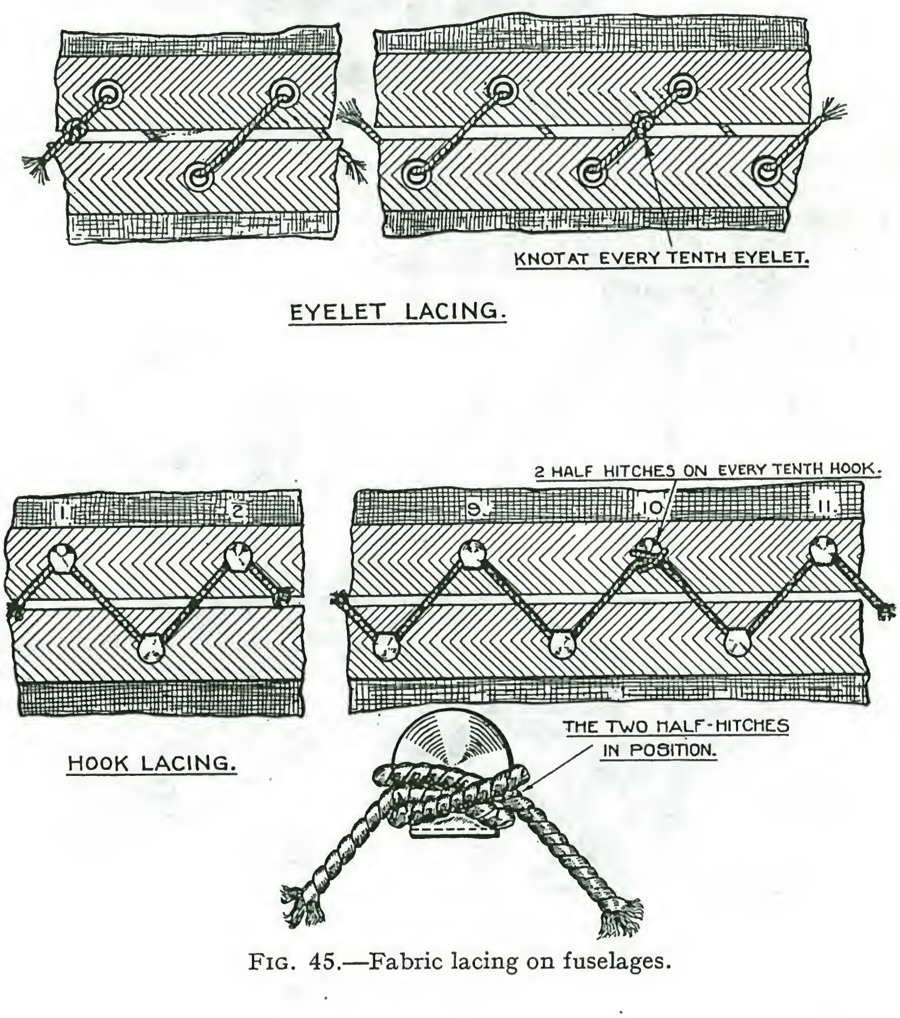


FIG. 45.—Fabric lacing on fuselages.

installation. The remainder of the fairing is composed of doped fabric laced on over some form of lightly built framework. The type of lacing employed is shown in fig. 45, the plain eyelet holes being preferable to the hook eyelets shown in the lower illustration.

Fittings on wooden aircraft.

154. Fittings for wooden aircraft are seldom machined from solid material, but are usually made up from plates or tubes bent to the desired shape, and where necessary welded, brazed, bolted or riveted together. The material from which the fittings are made varies with the purpose for which the fittings are designed, but they are generally composed of steel. Figs. 33, 41 and 44, show some typical fittings. Occasionally a light alloy, such as duralumin, or one of the non-ferrous alloys is used. High-tensile steel is very seldom used, except for such parts as wiring lugs, as it is usually necessary to have a comparatively large area of plate in contact with the wooden members, and the size of the fittings being large on this account, sufficient strength is generally provided by low-tensile material. Large contact areas are required between the plate fitting and the wood in order to reduce the bearing pressure between the wood and the metal to a pressure which is suitable for the timber, or if a number of wood screws are used for attachment, to obtain adequate spacing of the screws. A reasonably large spacing between the screws is necessary to avoid splitting the wood, and also to obtain a good distribution of the transferred load.

155. Plate fittings are made from one piece of comparatively thick material or from two or more pieces riveted, edge-welded, or otherwise connected together, and the plates are either left solid or lightened out. If low-tensile material is utilised for wiring lugs, then it is usually unnecessary to take any special measures to give a sufficient bearing area for the pins or other attachments, but where it is found essential a pad is welded, brazed, sweated or riveted on to the main plate, as shown at A, fig. 46. In other cases a special large-diameter pin is used as given at D. Where high-tensile steel is used for wiring lugs attached to low-tensile fittings, the connection is made by riveting, or by placing the high-tensile plates under the heads of one or more of the attachment bolts, or, in many instances, by adopting both these measures as indicated at E, fig. 46. If the high-tensile material is thin, then an adequate bearing area is obtained, by some designers, by riveting steel eyelets of lower tensile strength into the pin hole as shown at B and E. Where the high-tensile material is comparatively thick, the lugs are usually made up as at C.

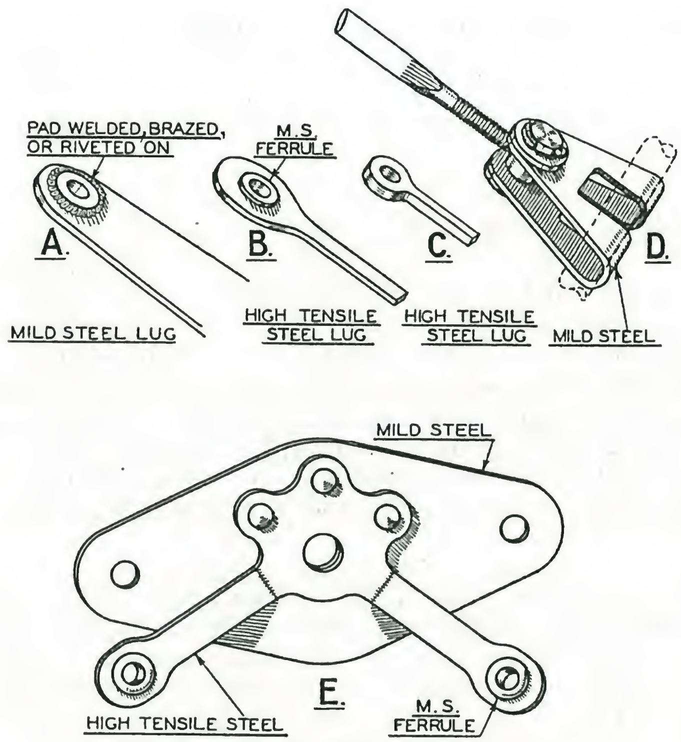


FIG. 46.—Wiring lugs.

Wooden undercarriages and tail skids.

156. Undercarriages for wooden or composite aircraft of modern design are generally of metal construction, and the details are therefore similar to those used for metal aircraft. Wooden undercarriages are to some extent still used and they do not vary greatly in their general design. The details may alter considerably, but in most cases, as shown in Fig. 47,

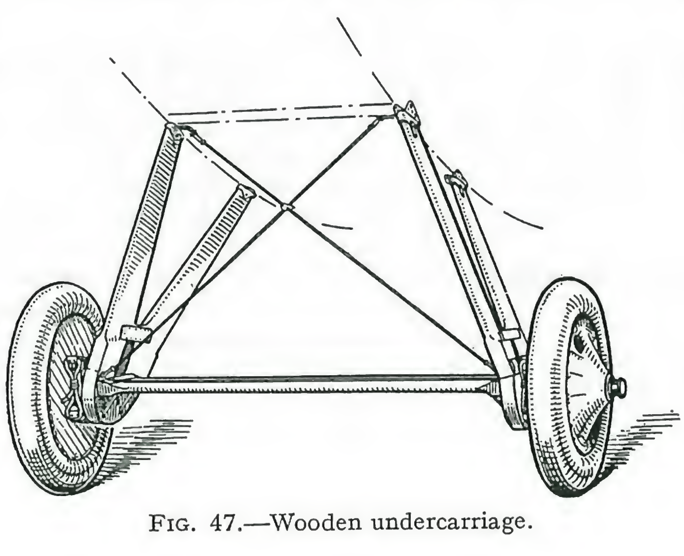


FIG. 47.—Wooden undercarriage.

wooden V-struts are used, braced transversely with diagonal wires. Elastic cord shock-absorbers are usually provided for the axle, which is allowed vertical movement, generally in guides formed in the bottom junction of the V-struts. The axles, which are usually covered by a wooden fairing, are formed from high-tensile steel tube, which has been specially prepared and heat-treated for the purpose.

157. Wooden tail skids are usually constructed of ash or similar hard wood and shod with steel plates. Rubber shock-absorbers are often provided arranged with the rubber either in tension or compression, but steel springs or oleo cylinders are common alternatives. Two examples are shown in fig. 48. The skids are in some cases made capable of following the track of the aircraft and in others the skid is made steerable.

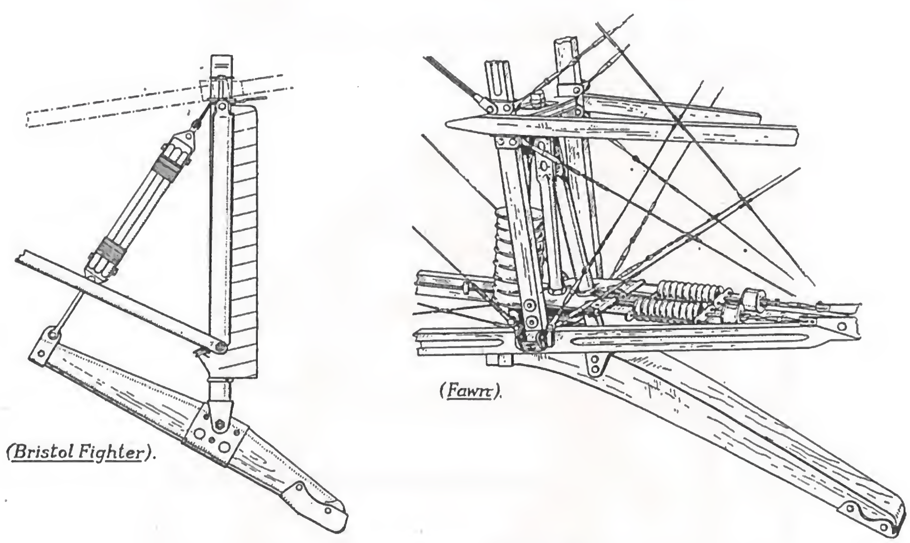
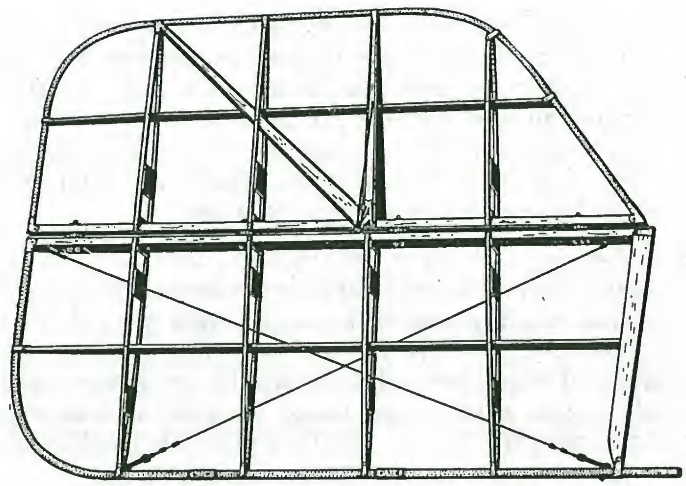


FIG. 48.—Wooden tail skids.

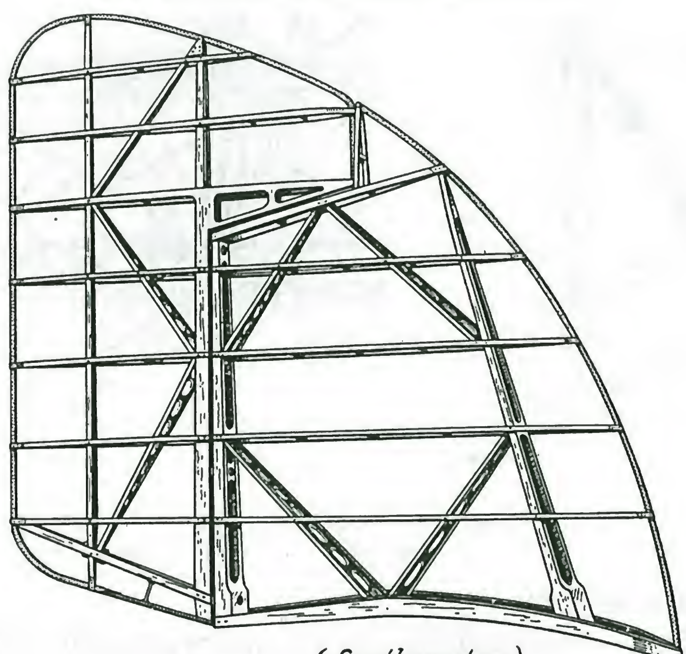
Wooden tail units.

158. Tail planes for wooden aircraft are generally made up in a similar manner to the main planes, having two wooden spars (usually of the solid spindled-out type) and wooden ribs. Some form of incidence adjustment is normally provided. The elevators usually have the same type of construction as the tail plane and are generally hinged to the rear spar by means of standard eye and fork end bolts. The fins and rudders follow much the same practice as the tail plane and elevators. Typical skeleton arrangements of a tail plane and elevator and a fin and rudder are given in figs. 49 and 50.



(Avro).

FIG. 49.—Wooden tail plane and elevator.



(Southampton.)

FIG. 50.—Wooden fin and rudder.

Wooden airscrews.

159. Wooden airscrews for service use are usually made up from mahogany to Specification 3V.7. Walnut Specification 3V.5 is also an approved material but is less frequently used. The majority of airscrews have two blades but when four-bladed airscrews are provided it is usual for these to be made up in two parts each having two blades and a boss of half

the normal thickness. The two halves are dowelled together and bolted to the airscrew hub at 90° to one another.

160. Wooden airscrews are built up in laminae, that is, there are six to eight separate planks which are glued and pressed together, each plank having an angular displacement with respect to its neighbour, much like a partly-opened fan. In this way the complete blade form can be evolved with the minimum amount of timber wastage. The planks used for the laminae are selected with great care, and are so cut that the grain of the wood lies as nearly as possible along the length of the blade, 1 in 15 being the maximum permissible grain inclination. The laminae are usually from $\frac{3}{4}$ in. to 1 in. in thickness. They must be unwarped and free from other defects.

161. Special precautions are taken with the gluing and pressing to ensure perfectly formed joints, and the surfaces to be glued are lightly grooved or scored with a special tool, prior to the application of glue or cement. When ready for shaping, the laminated block is usually roughly shaped in a special profile machine which cuts away the surplus timber and reduces the block to approximately the dimensions required. The finishing off is normally done by hand. After shaping and before subsequent operations, the airscrew is subjected to an inspection for defects and general finish, including angles, dimensions, track, alignment, balance. After boring and drilling, the identification marks are stamped on the periphery of the boss between the blades. The identification marks consist of drawing and issue numbers, with prefix or suffix letters, if any, the diameter and pitch (prefixed by the letters D and P respectively), name and series of engine, serial numbers, month and year of manufacture, and the approval stamp of the authorised inspector.

162. A metal sheathing is attached to the blades, which covers the leading edge for about the outer two-thirds and extends round the tip. This sheathing is secured to the blades by wood screws or rivets, the heads of which are sunk slightly below the surrounding surface of the sheathing, and are finally flooded over with soft solder. The object of the sheathing is to protect the airscrew from damage caused by rain, sea-water or spray, and by the small stones and other matter which may be drawn into the airscrew disc. It is essential that airscrews should be coated with a waterproof protective. The usual protective materials are fabric, glued on and covered with several coats of the best coach varnish, or cellulose lacquer. The latter substance is applied in the manner described in Air Ministry Technical Order 404 of 1929, four coats of undercoating, Stores Ref. 33B/52, being applied and three coats of finishing lacquer, Stores Ref. 33B/53, before the sheathing is attached. The sheathing itself is given three coats of finishing lacquer after being secured to the blade.

CHAPTER VI.

METAL CONSTRUCTION.

General description.

163. The development of all-metal construction has been greatly facilitated by the introduction of the many and diversified kinds of materials now available. Much attention has been devoted during recent years to the production of steels and non-ferrous alloys on a commercial basis in a suitable form for aircraft construction, and these materials can now be obtained in a variety of forms and conditions which allow a wider choice of material possessing the required properties, and consequently give a greater freedom in design. Aircraft which are of fundamentally good design, and which, apart from the fabric, are composed entirely of metal, should require less work on erection, rigging, and general maintenance and repair than similar wooden structures, but, on the other hand, much closer attention to detail is required for metal aircraft under normal service conditions.

164. All-metal construction provides a rigid structure that is relatively durable, and which can be made to comparatively fine limits. All the attachments and connections are metal to metal, and are therefore definite; also, accurate interchangeability of parts is easily obtained because the materials lend themselves readily to precise measurement and consistent reproduction. Two of the greatest enemies of metal construction are vibration and corrosion, and the utmost care is always taken during manufacture to eliminate as far as possible any likelihood of failures due to these causes, but it is necessary to be very attentive during inspection to detect any actual or incipient fractures, elongation of holes, or oxidation. For all structural purposes the metals used on aircraft are practically unaffected by changes of climatic condition, but they are subject to surface oxidation and other forms of corrosion unless reasonable care is taken for their preservation. The various measures taken to prevent corrosion are discussed in detail in a later chapter, but broadly the methods consist almost entirely of the preparation of the surface of the metal in such a manner as to prevent contact with the atmosphere.

165. The types of construction used for metal aircraft may be classified as strip steel, tubular steel, and light alloy. For the details of construction of any particular aircraft, reference should be made to the aircraft handbooks which are specially provided to supply this information.

Strip steel.

166. A strip steel structure of good design is strong, rigid, and light, but on account of the fact that very thin and high-tensile materials are used, it is susceptible to damage if roughly handled. Corrosion and fatigue failures must also be guarded against as, owing to the thinness of the materials employed, failures due to these causes are more probable than when heavier gauges of material are used. Strip steel construction is not normally used throughout the aircraft, but is confined to the planes and other parts where, by its use, an advantage is obtained over tubular or other forms of construction. Also, although an aircraft may be built mainly of steel, other materials such as aluminium or duralumin are used for fairings and similar sub-structures, if there is a distinct benefit derived by so doing.

167. The strip steel material is obtained from the steel manufacturers in long lengths, or strips, which are of the requisite gauge and only slightly wider than is required for the finished article. The strip is pulled through dies, or specially shaped rollers, which force the steel into the required shape. Then the formed strips are riveted or otherwise connected together and trimmed up, and so form the various sections used on different parts of the aircraft. An infinite variety of sections may be produced by this means. The gauges of the steels used depend to some extent upon the purpose for which the finished part is to be employed ; gauges between 24 S.W.G. and 30 S.W.G. are common, but, for practical reasons, gauges below 33 S.W.G. are seldom, if ever, used. The tensile strength of the material varies between 60 and 80 tons per sq. in., depending upon the specification used. Built-up strip steel sections can be used for any of the members, though their use is normally confined to spars and certain forms of strut.

Non-corrosive steels.

168. Stainless steels are employed mainly on those aircraft subject to conditions conducive to excessive corrosion, such as contact with sea air or sea water. Although it is obviously the ideal material, aircraft are not usually built entirely of these steels owing to the cost and the difficulty of obtaining the materials in the exact form required.

169. Several forms of non-corrosive steel are produced which are all more or less successful in their non-corrosive properties. In other respects, taken as a whole, they are not quite so successful as ordinary steels, as in some instances there is a little difficulty in working or machining, and in others the heat treatment required to give the tensile strength has a

somewhat critical value, and demands considerable care. Nevertheless, in spite of the consequent higher technical skill required in working, considerable use is being made of this material.

170. Non-corrosive steels are used mainly for fittings, wiring lugs, and similar highly stressed parts which are exposed or otherwise subjected to corrosive conditions, the failure of which would involve the possible collapse of the structure. These materials are also used for contact faces, such as bearings, where the inter-action between the materials is liable to induce excessive corrosion. This point is dealt with more fully in paras. 416 to 419.

Solid drawn tubes.

171. Solid drawn tubes are perhaps the most frequently used form of material for metal aircraft construction. This is because for many parts, especially struts, round tubes are the most economical shape, and also because other than providing an end attachment, there is little or no work to be done on them, and they can be easily adapted to the type of structure required. Solid drawn round tubes are obtainable in practically any material, diameter, and gauge, and also special sections of many varieties, such as square and streamline, are made to suit particular purposes.

172. Square tubes are often used on fuselages in conjunction with flat side plate fittings, and combine well with wood when necessary. Streamline and oval tubes are used as struts in certain external positions, usually where a built-up form of strut would not be an economical proposition, or where it is subjected to rough treatment.

Light alloys.

173. Light alloys are composed mainly of aluminium or magnesium, and have a low specific gravity. On account of their unstable nature and low tensile strength, pure aluminium or magnesium is seldon used, except for sub-structures and fairings, but alloys of these materials, such as duralumin, are used extensively.

174. Duralumin is a metal consisting mainly of aluminium with the addition of a little copper and other substances, which gives the material, in its hardest state, a strength comparable with mild steel. Duralumin derives its hard, tough condition owing mainly to the rolling and other working processes during manufacture. It can be easily machined, but needs heat treatment before it can be safely bent, or worked in a like manner. The heat treatment of duralumin is dealt with in Air Ministry Technical Order 361 of 1930. Duralumin

can be obtained in all the usual forms and sections, such as forgings, sheets or tubes, and the general design of the structure employing this material does not vary greatly from the design used for steel structures, excepting that duralumin is not welded or soldered owing to the fact that it suffers a great loss of strength if excessive heat is applied to it.

175. The greatest drawback to the use of duralumin, or any light alloy, is corrosion. The corrosion is not confined to surface oxidation only, but is inter-crystalline, a form of corrosion which may, or may not, present surface indications. This subject is more fully treated in a later chapter.

176. Duralumin fittings and other parts are usually thicker and larger than corresponding steel fittings. This is on account of the fact that a high working stress is not allowed for this material, 16 tons per sq. in. being the generally accepted figure. There would not be a great deal of difference in the weight of precisely similar members when constructed in either steel or duralumin, but as the duralumin parts would be thicker and more bulky to give the equivalent strength, they would probably be more stable under load, and more resistant to accidental damage.

Welded structures.

177. Oxy-acetylene welding is extensively used in modern aircraft, especially for the smaller plate fittings, as by its use an extremely cheap and homogeneous part is provided. The main disadvantages against welding are that the process usually alters the character and reduces the tensile strength of the metal in the neighbourhood of the weld, and also, without actual test, it is not always possible to ascertain if the material has been slightly burnt or if it has been completely welded right through.

178. Aircraft on which welded structures are utilised find considerable favour in some quarters, more particularly abroad than in this country, mainly on the score of low cost of production and ease of maintenance. Welded structures are permitted on service aircraft provided that materials of the correct specification are used, and other necessary restrictions are observed. The general conditions governing welding by aircraft manufacturers is dealt with in a later chapter, but broadly, the restrictions are that the failure of any one welded joint must not involve the collapse of the structure, and also that the maximum tensile stress encountered must not exceed 66 per cent. of the strength of the material before welding.

179. There are many instances to be found of the welding of small parts, and those shown in fig. 51 are given merely

to show the kind of work done by this process. The upper illustration of fig. 59 can also be referred to as an instance of a welded fuselage.

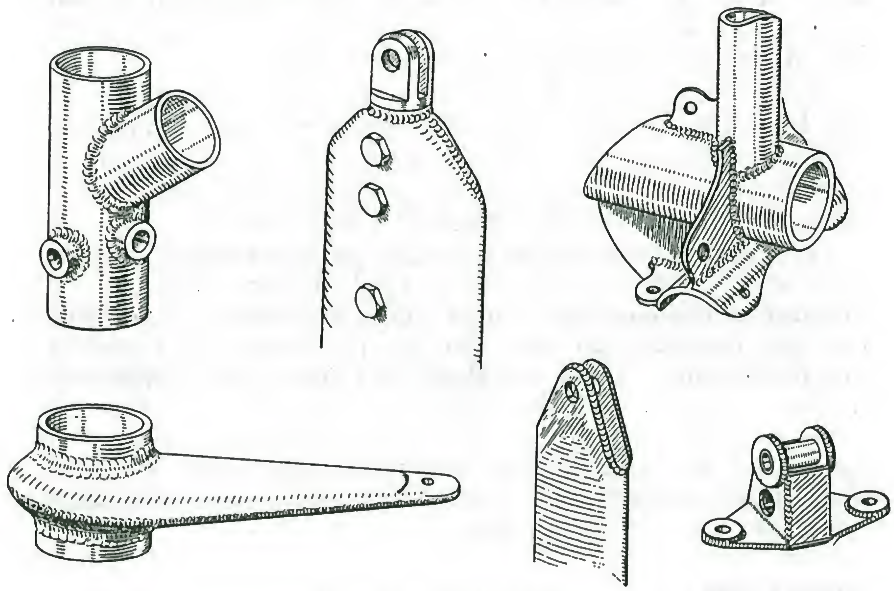


FIG. 51.—Welded parts.

Metal planes.

180. The production of a sound design of structure for a metal wing, which was to be no heavier than a corresponding wooden wing and equally as strong, was the cause of considerable experimenting before success could be claimed, and is still the subject of much investigation. The necessity of providing the lightest possible structure forced the designers into using high-tensile steel or light alloy, and metal wings are constructed of either of these materials or a combination of both. The most successful designs which have been adopted for service use conform in a great measure to the normal arrangement of the wooden two-spar construction, and therefore there are approximately the same number of members, placed very much in the same relation to one another. The greatest difference, apart from materials, is in the detail design of the parts. There are other forms of construction, notably the multi-spar and the mono-spar types shown diagrammatically in fig. 29, but, owing to the fact that they are typical cantilever wing designs, it is doubtful if these types will ever supersede the two-spar design for biplanes.

181. As in the wooden type of construction, the most important members in a metal wing are the spars. With wooden spars, the actual volume of material required for

strength, the space available within the wing, and the usual woodworking methods of construction employed, restrict the design within definite limits. With metal spars, on the other hand, the design varies to a considerable extent, owing to the fact that the space available is the same, but the bulk of the material is far less, which allows the designer greater liberty of choice in the disposal of it. The materials used for the construction of metal wings may be in the form of tubes, or they may be flat sheets or strips which are pressed, or otherwise worked, into the desired shapes and sections. The normal method of attaching the various parts together is by riveting or bolting, mainly the former. Welding or brazing is very seldom employed, as the materials normally used are not suitable for these processes. Soldering also is seldom used, except for the attachment of tube end sockets. Fig. 52 represents a section from a wing which is mainly constructed from strip sheet.

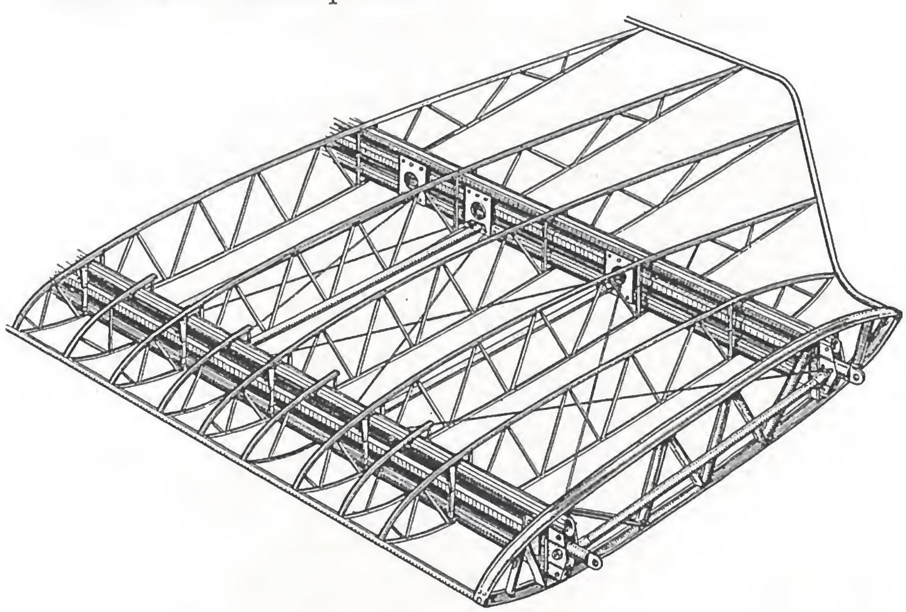


FIG. 52.—Section of metal plane.

Lateral control surfaces.

182. There are several forms of lateral control surfaces for aircraft, but the more usual form is that of the aileron, or hinged wing flap, which forms part of the actual wing surfaces aft of the rear spars. Control is obtained by simultaneously raising the aileron on one side and lowering the other, and accordingly diminishing or increasing the lift. As the movement of an aileron is obtained by pulling or pushing one or more levers attached to the aileron structure,

it is necessary that it should be strong enough to withstand the torsional effects so produced. Ailerons are therefore provided with a spar member of tubular or other form, which normally also forms the attachment points for the hinge. In other respects the construction follows the general lines employed on the wing to which it is attached. Fig. 53 shows a normal type of "Frise" aileron in which the hinges are placed some way back from its leading edge. In this type, in addition to the aerodynamic advantages already described in para. 28, the torsional loads are reduced by placing the hinge approximately at the centre of pressure of the aileron.

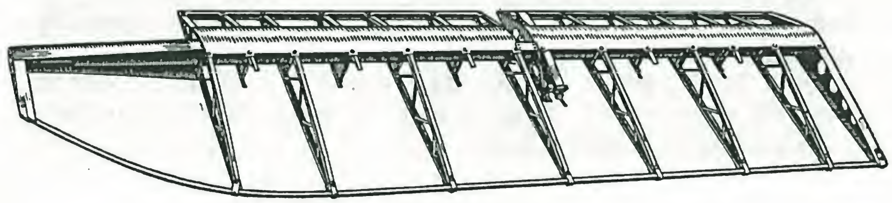


FIG. 53.—Frise aileron.

183. Another form of lateral control is that of the automatic slot. Fig. 54 shows a normal arrangement of slot, the action of which has already been described in paras. 31 and 32.

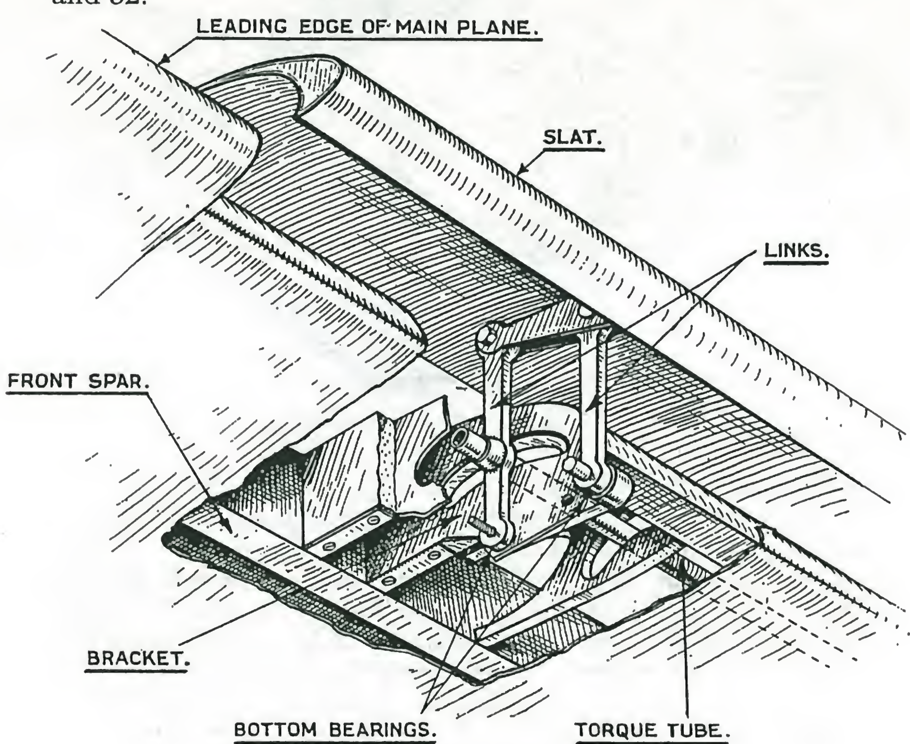


FIG. 54.—Automatic slot construction.

Metal spars.

184. The simplest form of metal spar used is that of the solid drawn round tube, but owing to the uneconomical distribution of the material, this form of spar is comparatively heavy. A much lighter form of spar can be made if the tube is reshaped by rolling, or if it is built up, and the material disposed to greater advantage. Built-up metal spars are made from strip steel or duralumin, the form being governed to some extent by the size and load they have to carry, but to an even greater extent by the type of construction adopted by the designer. Fig. 55 shows some of the types of steel spars used. All the spars shown are suitable for large or small aircraft, excepting the top left-hand illustration, which shows a type of design particularly suitable for the large types.

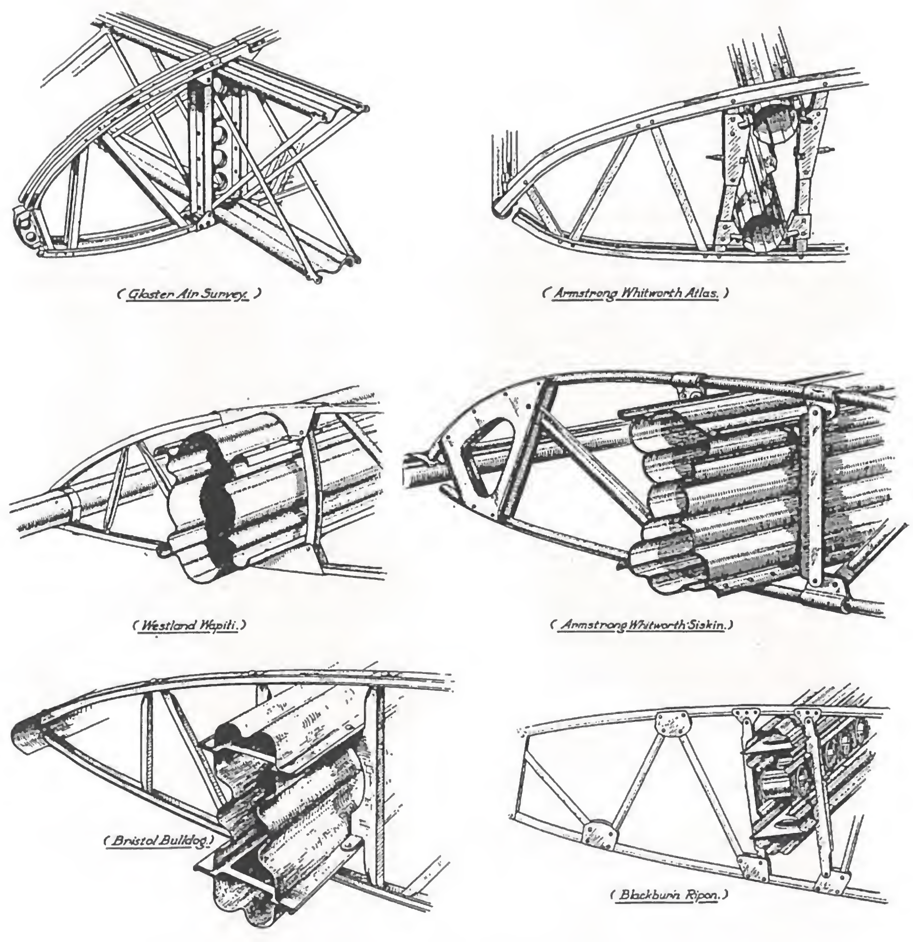


FIG. 55.—Steel spar sections and rib attachments.

Fig. 56 shows some of the types of duralumin spars used, and, as will be noted, the designs are somewhat more open in section, due to the fact that, strength for strength, duralumin is thicker and more bulky than steel, and therefore more stable under load. The designs shown are applicable to all types of aircraft, with the exception again of the top left-hand illustration, which is more suitable for the larger aircraft.

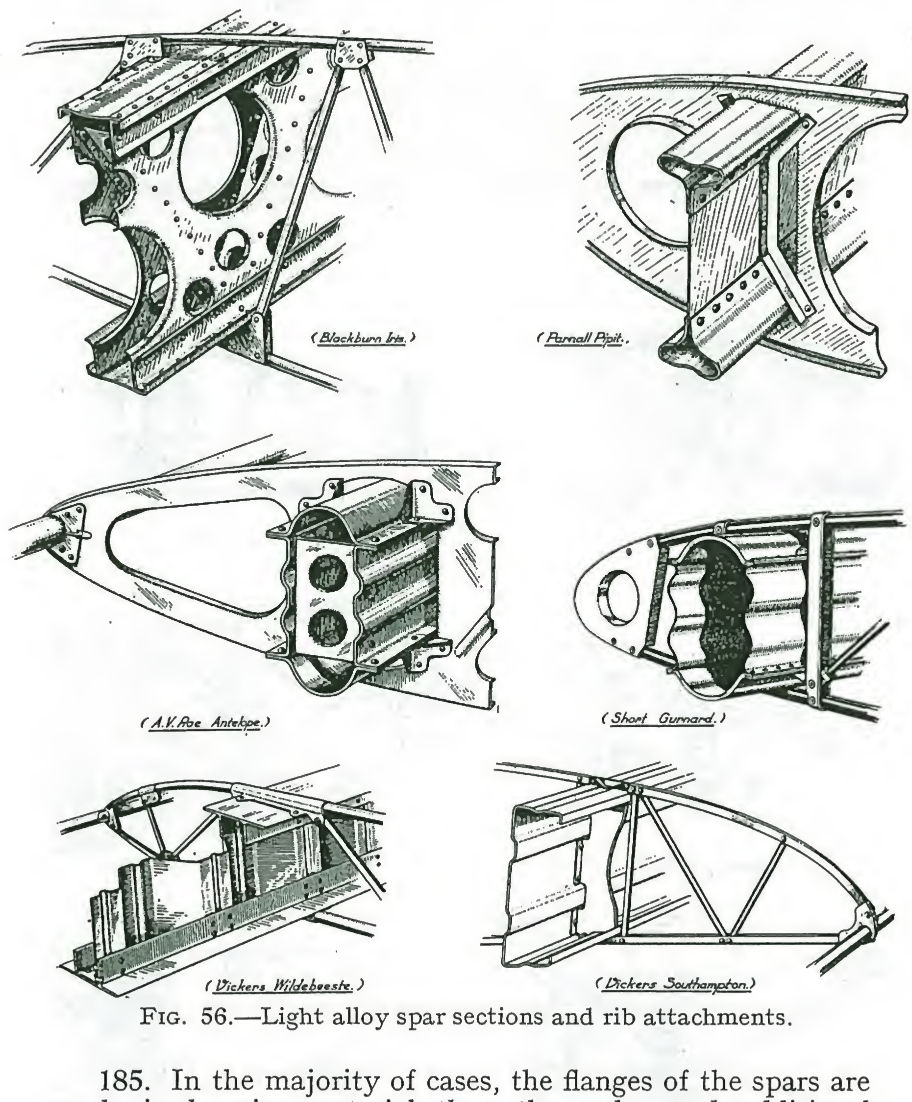


Fig. 56.—Light alloy spar sections and rib attachments.

185. In the majority of cases, the flanges of the spars are made in heavier material than the webs, and additional flange or web plates are used at the attachment points of the spars, in order that the stress may be as uniform as possible throughout the length of the spar under any normal condition of loading.

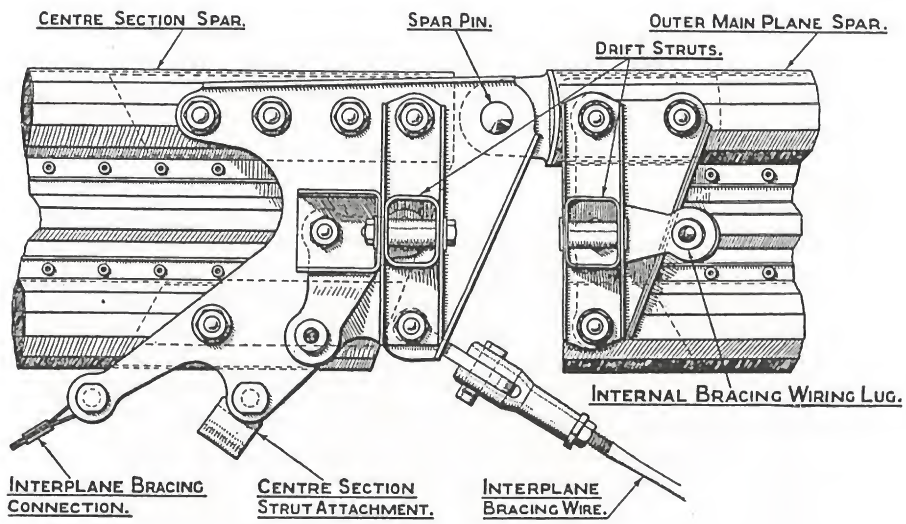


FIG. 57.—Metal spar end fitting.

186. The form that the spar attachments take varies with each design of spar, but they can roughly be separated into two types, those employing side plates, and those where the attachment is made directly to the spar surfaces. In the latter case, there is usually some form of internal fitting or bulkhead plate. Figs. 57 and 58 illustrate both these methods.

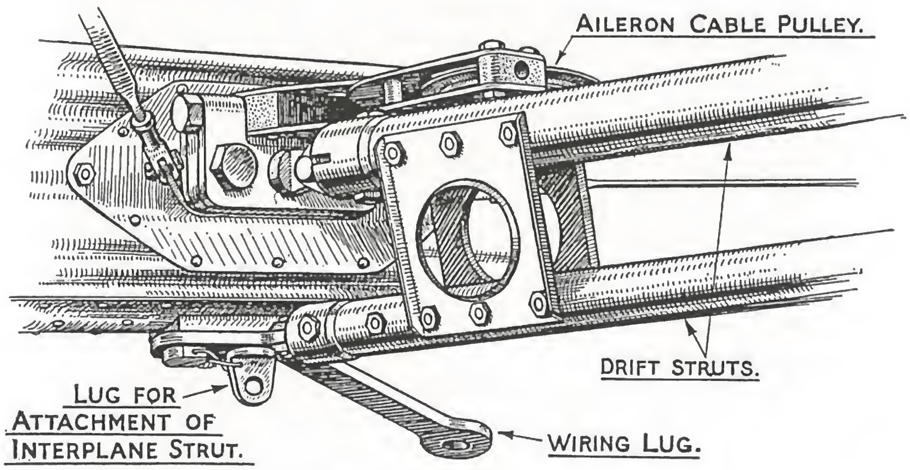


FIG. 58.—Metal spar fitting.

Metal ribs.

187. It is not unusual for light alloy ribs to be used with steel spars, but it is a more common practice for steel ribs to be used. The construction of metal ribs and the method of attachment to the spars are shown in figs. 55 and 56. It will

be noted that in some designs ribs are riveted or bolted on to the spars, whereas in others some form of flexible spring clip is employed. The flexible type of attachment is used with the intention of damping out any excessive vibration in the wings, which may be transmitted from the engine.

Metal fuselages.

188. The members of all-metal fuselages may be composed entirely of steel or duralumin, or may be a mixture of both. On account of its easy adaptability for the purpose, solid drawn round or square tubes are to a great extent used for metal fuselage construction, especially the front end, but different forms of construction are sometimes utilised for the rear portion. Strip steel is seldom used throughout the complete fuselage because, if the weight is kept down to a minimum, it is not always a suitable type of construction to withstand the rough handling which may be encountered in cockpits and engine mountings, and also the many attachments required are not so easily made to this type of structure as to the tubular form.

189. Fuselage structures may have pinned joints, or may be constructed with fixed-ended struts, and the joints may be riveted, bolted or welded together, but in all cases it is customary to employ jigs during manufacture, in order to ensure that the structure will be true when completed. Fig. 59B shows a pin-jointed fuselage construction, employing ball-ended struts which are maintained in position in the cap sockets by the bracing wires. Fig. 60A shows also a tubular type of structure with fixed-ended struts riveted by side plates to the longerons. Fig. 60B shows a typical strip steel type of fuselage, and fig. 59A represents the welded type.

190. The fuselage fairings are arranged in a very similar manner to those for wooden aircraft, but the formers and solid fairings are normally made of light alloy instead of three-ply. The formers are composed of sheet material or of small diameter tubes, and are bolted or clipped to the fuselage members.

191. In addition to the braced forms of fuselages illustrated, there is the monocoque type of construction shown in fig. 61. In the type illustrated, the structure is made of sheet duralumin rings or sections, reinforced between the formers by stiffeners.

Metal struts.

192. Whenever they can be economically used, solid drawn round tubes are employed as struts, with the addition of some form of fairing to reduce the head resistance if they are used externally. When struts are very long, some reduction in weight can usually be made if they are built up from sheet

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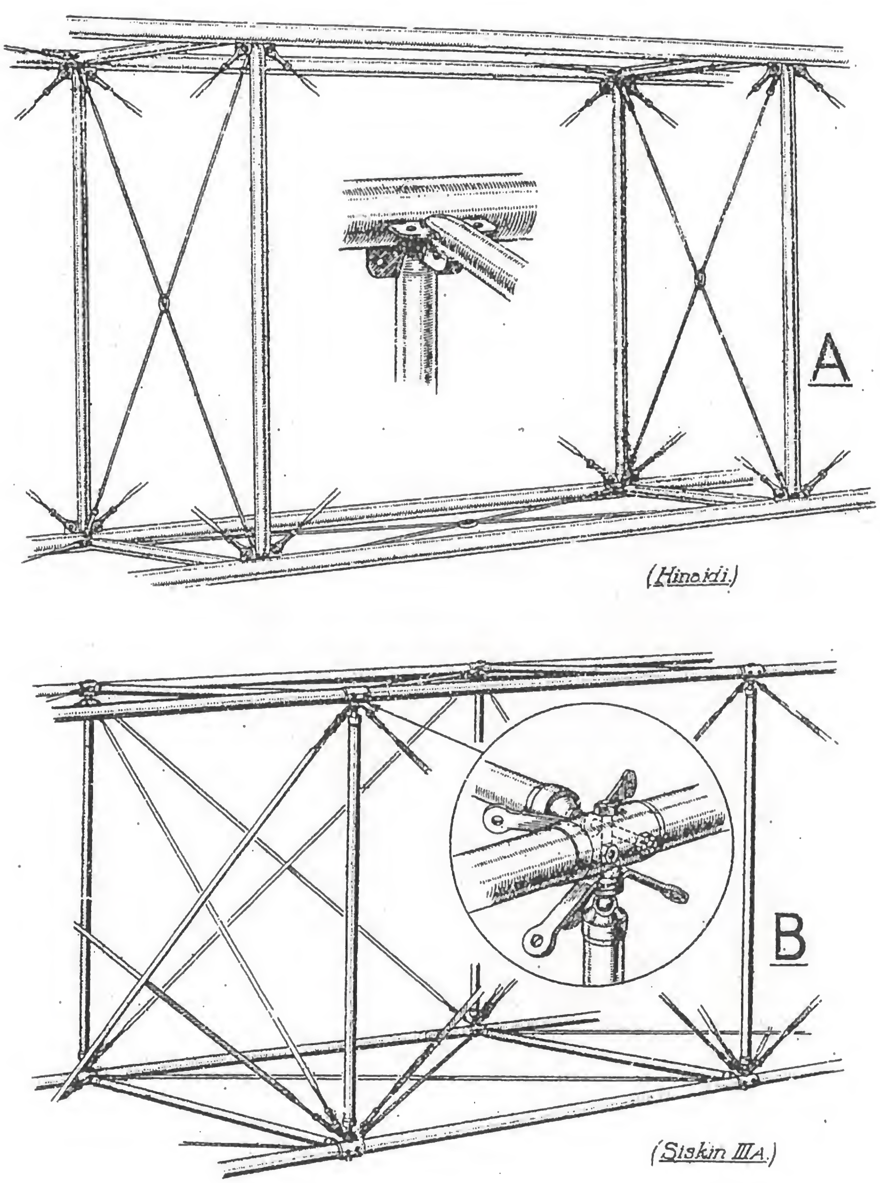

FIG.59. TYPICAL METAL FUSELAGES.— I.

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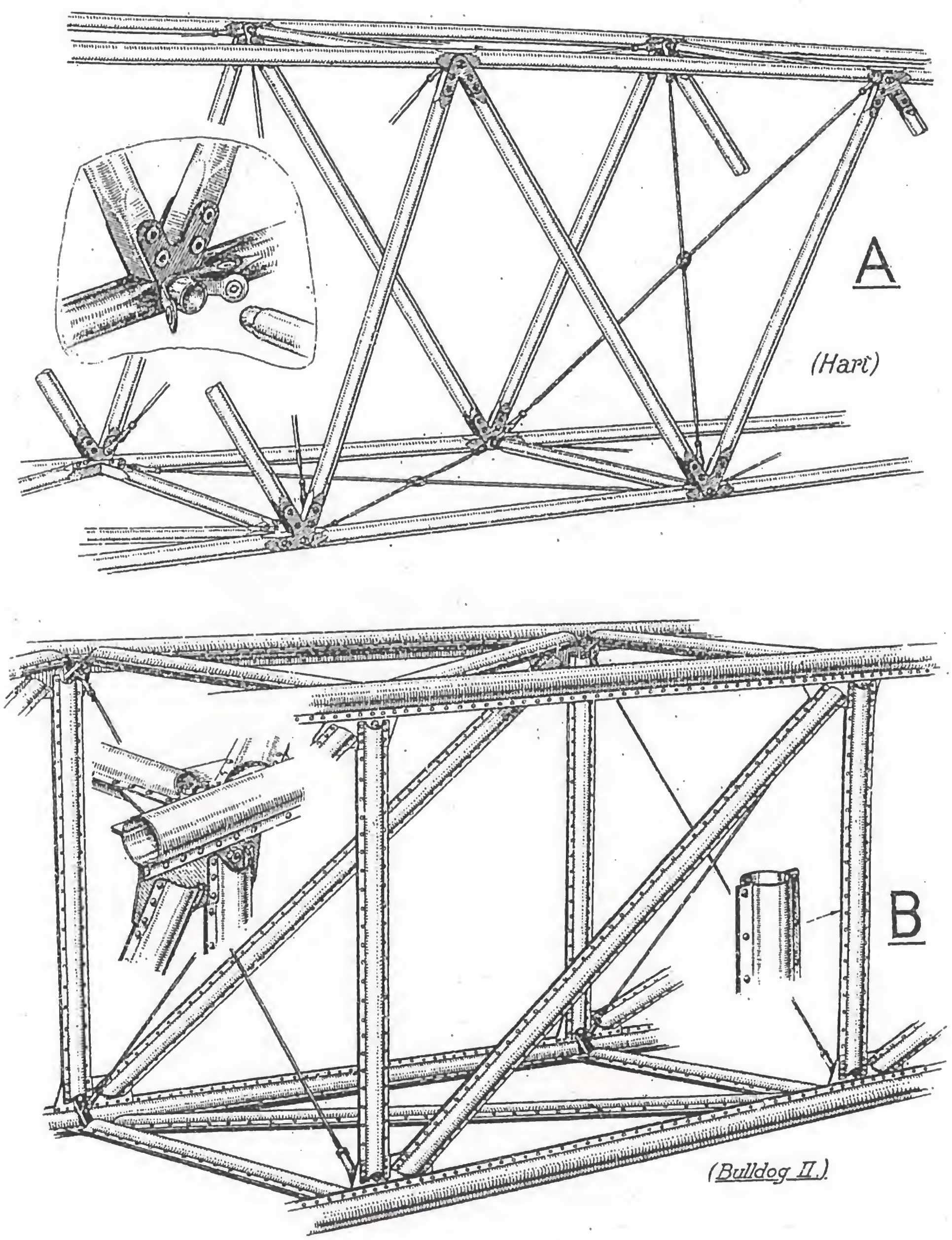

FIG. 60. TYPICAL METAL FUSELAGES.—2.

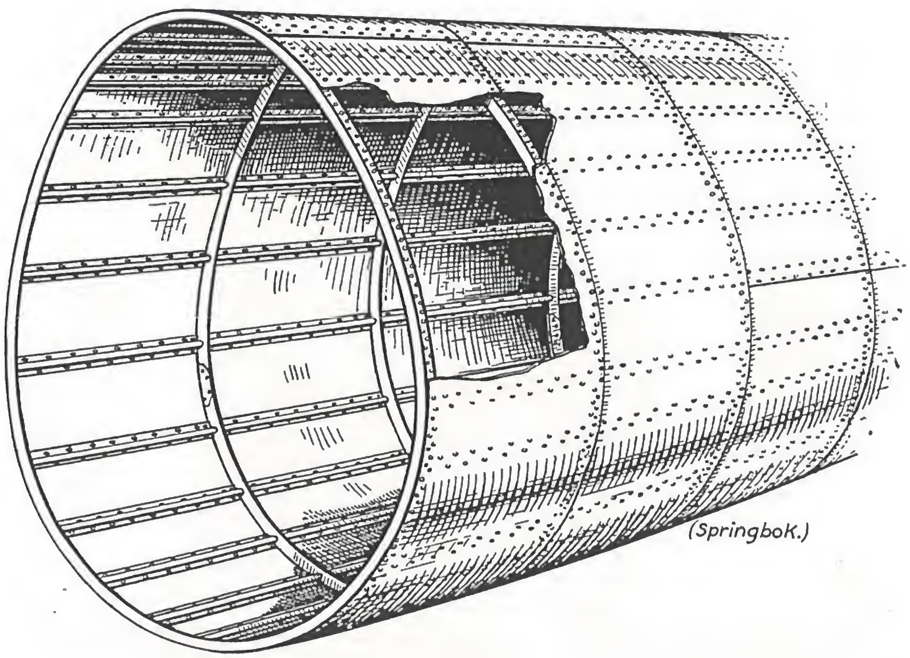

FIG. 61.—Metal monocoque construction.

or strip materials, as indicated in fig. 62. Occasionally, it is convenient to use one of the streamline section tubes which are obtainable in many shapes and sizes, but as these special section tubes are fairly heavy compared to their strength as struts, they are generally used only for the shorter and more heavily loaded struts, such as are met with at the centre sections or undercarriages, or where, owing to their small size, it would be uneconomical to use a built-up form.

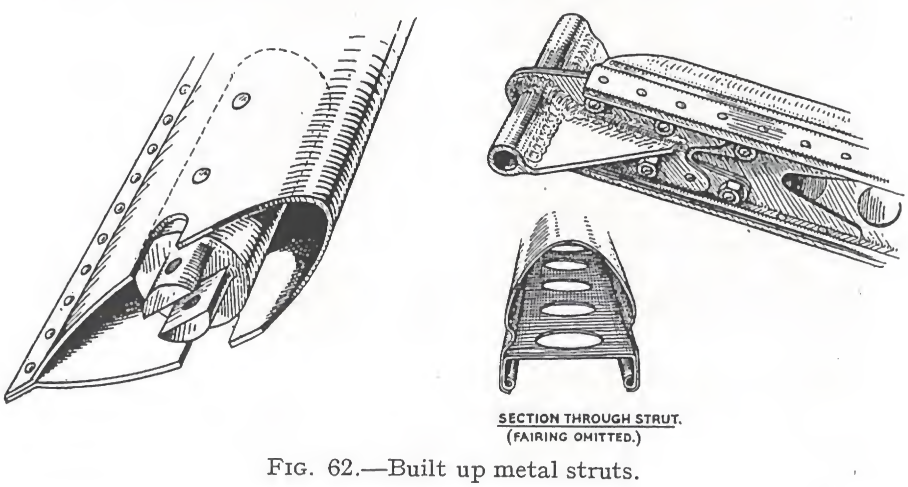

FIG. 62.—Built up metal struts.

193. The end fittings for tubular struts vary in design to some extent in accordance with the purpose for which the strut is used, but the most common type for pin-jointed structures is that of the internal or external socket shown at A and B, fig. 63, the latter being generally considered the better type, as it prevents any tendency of the tube to spread or split. Steel tube end sockets are a comparatively heavy type of

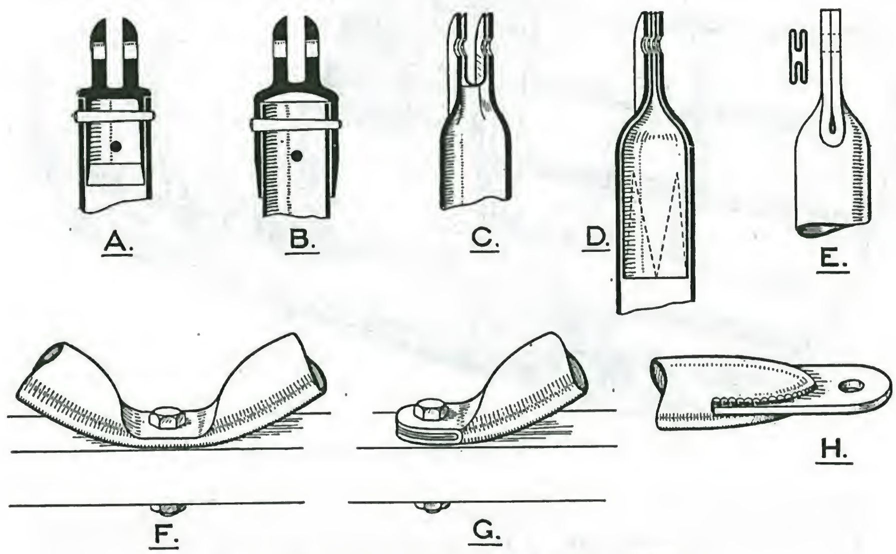

FIG. 63.—Tubular strut end attachments.

fitting, and for this reason manufacturers occasionally adopt other means of making tube end attachments. The illustrations C to H, fig. 63, give some of the methods used. The bent, flattened tube types are not frequently encountered on all-metal aircraft, because, even when the tube has a liner, a fracture is apt to occur at the bend, owing to the fact that the strut is offset from its attachment.

194. Fixed-ended struts are used extensively in fuselage construction, though seldom elsewhere. The advantages of fixing the ends of struts are reduction of weight and increased rigidity and lower production costs, but if the structure deflects greatly under load, then some of the benefits are lost owing to the necessity of making many of the members strong enough to take the bending thrown upon them by the fixed strut ends, as explained in para. 113. Examples of fixed-ended fuselage struts are given in fig. 59 and fig. 60.

Metal tail planes and elevators.

195. The method of construction of tail units is, in the majority of cases, similar to that used for the main planes, the main differences being that the tail planes are much

smaller in span, and usually have a symmetrical section. Also, all that portion of the plane behind the rear spar is usually hinged, and so forms the elevators. The stripped tail-plane and elevator shown in fig. 64 represents one type of strip steel construction.

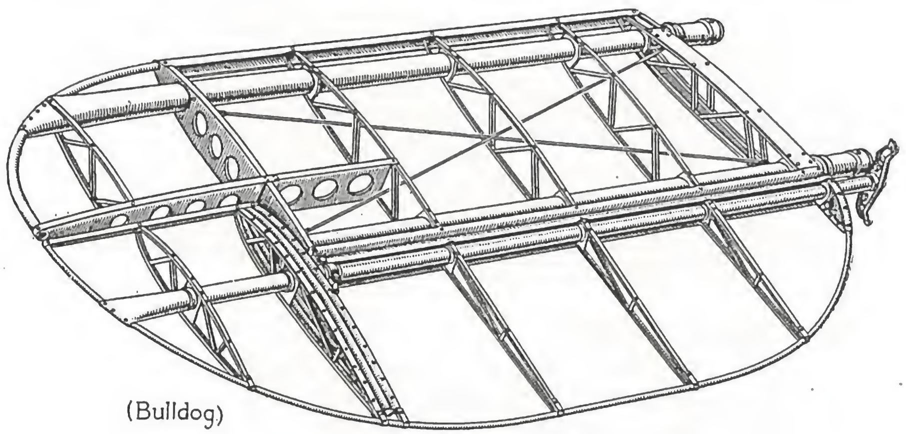

FIG. 64.—Metal tailplane and elevator.

196. Tail planes are usually provided with some form of incidence adjustment which is operable in the air. The tail adjusting gear shown in fig. 65 indicates the principle on which

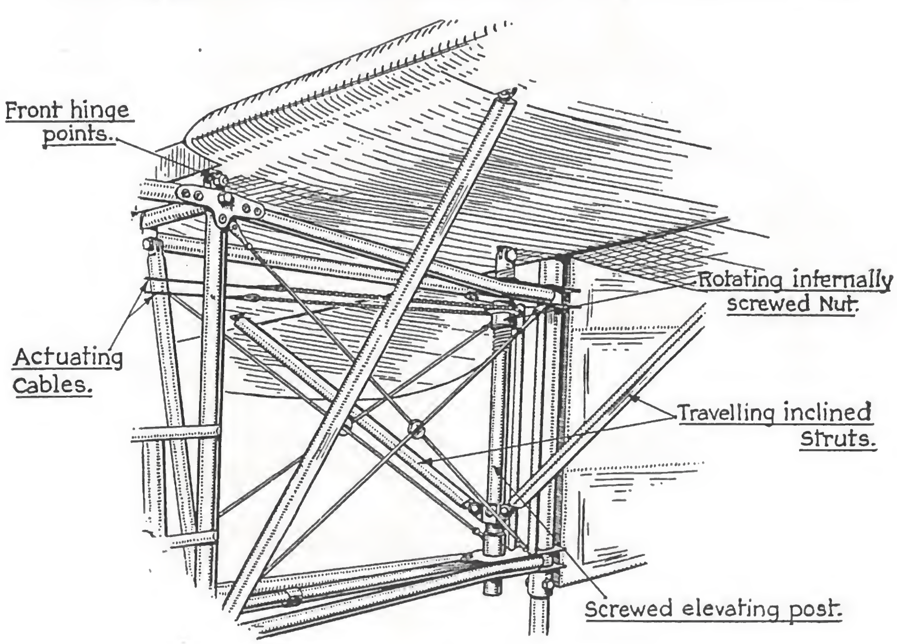

FIG. 65.—Tail adjusting gear.

the majority of these gears work. The object of the device is to give a fairly large range of adjustment of incidence for the tail plane, so that, under all normal conditions of flight and centre of gravity positions, the air loads can be to a great degree balanced, thereby making the aircraft less tiring to fly.

197. The elevators are generally provided with some form of balance, and are usually directly connected together by being mounted on the same spar, but variations of this arrangement exist where the inter-connection is obtained by having a countershaft fitted with levers, positioned in the rear end of the fuselage with connecting rods to a lever on each elevator. The reason for the rigid inter-connection is to prevent the excessive tail flutter which may be produced by elevators connected only by cables.

Metal fins and rudders.

198. Fins and rudders are usually built in a slightly different manner from the main planes. The type of construction used is generally much simpler. Fig. 66 shows a

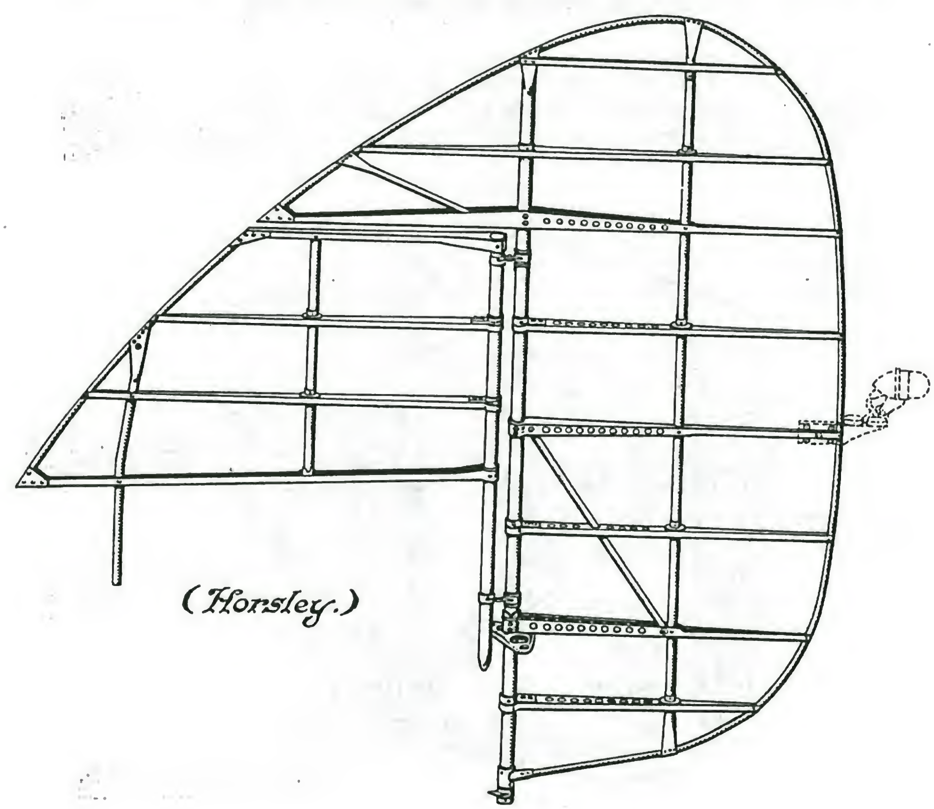

FIG. 66.—Metal fin and rudder.

skeleton arrangement of a fin and rudder employing steel tubes and light alloy ribs and boundary tubes, which is a usual type of design. As with ailerons and elevators, rudders are usually arranged with some form of balance in order to assist the pilot in actuating these control surfaces.

Metal undercarriages.

199. All the main members of an undercarriage for a modern aircraft are constructed of metal, but wooden fairings are still used for tubular axles or struts. The axles are in all cases composed of a high-grade tubular steel, specially hardened and tempered to withstand the landing shocks and also the bending stress which usually exists owing to the slightly offset wheels. In some instances the axle tube is in one continuous length, and in others it is split into two lengths, in which case the inner ends of the two halves are anchored to some point of the fuselage structure and the outer ends are set horizontally and sleeved to take the undercarriage wheels.

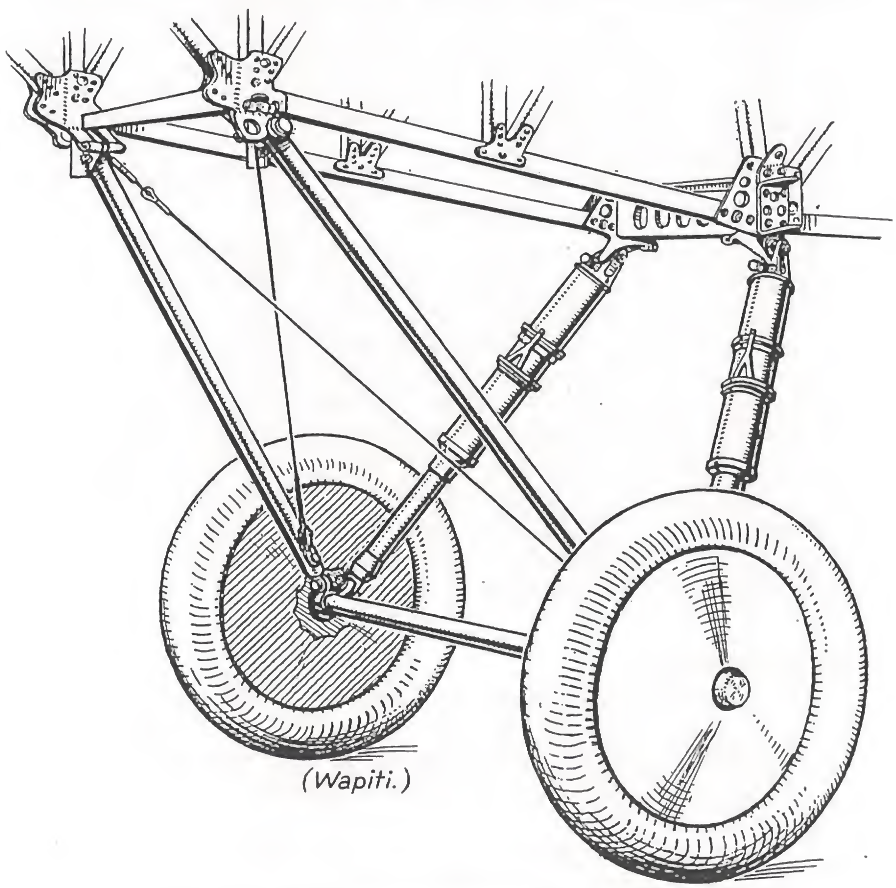

FIG. 67.—Metal undercarriage with through axle.

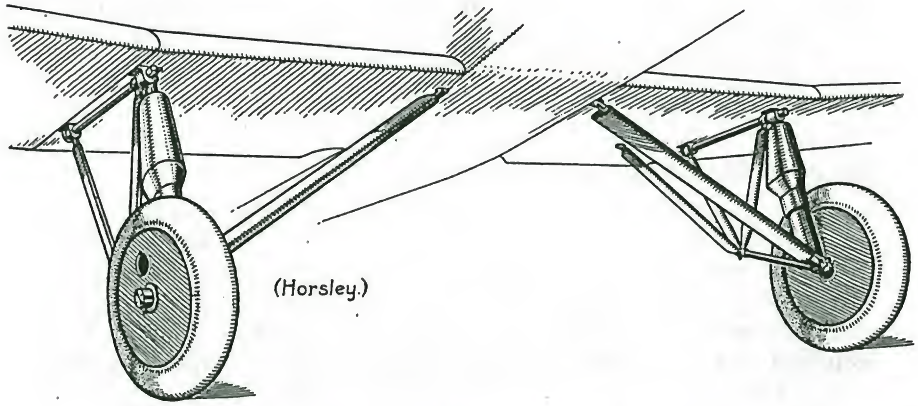

FIG. 68.—Metal two unit or divided undercarriage.

200. Figs. 67 and 68 show typical examples of both forms of undercarriage. In fig. 67, the undercarriage is of the oleo type with a through axle and V-struts, the rear struts being oleo legs, and the cross braced front struts acting as radius rods. The cross bracing in this case takes any side loads imposed. Fig. 68 shows a two unit or divided undercarriage, in which triangulated strut pylons take the fore-and-aft drag of the wheels, acting through short universally-jointed struts, and the axle takes the side loads.

Both these types of undercarriage may be fitted with wheel brakes, of which there are several types. The brakes are in most cases similar to those used for motor cars, that is, they may have an external band or internal shoes and may be operated by hand lever or foot pedals. The power may be transmitted indirectly by oil or air pressure or directly by cables or rods. Whatever form the mechanism takes, the brakes are usually arranged to operate on all wheels together or each side independently, as desired. The adjustment and maintenance of the various types are usually given in the Rigging and Maintenance Notes, or the Handbook, of the particular aircraft concerned.

Shock-absorbers.

201. If shock-absorbers are properly designed, they are efficient over all the conditions of loading of the aircraft to which they are fitted, but owing to the restriction on weight and range of movement this ideal is seldom realsied. It is not uncommon for shock-absorbers to be so designed that their maximum efficiency is obtained near the full load condition of the aircraft ; this tends to produce harsh action under light loads.

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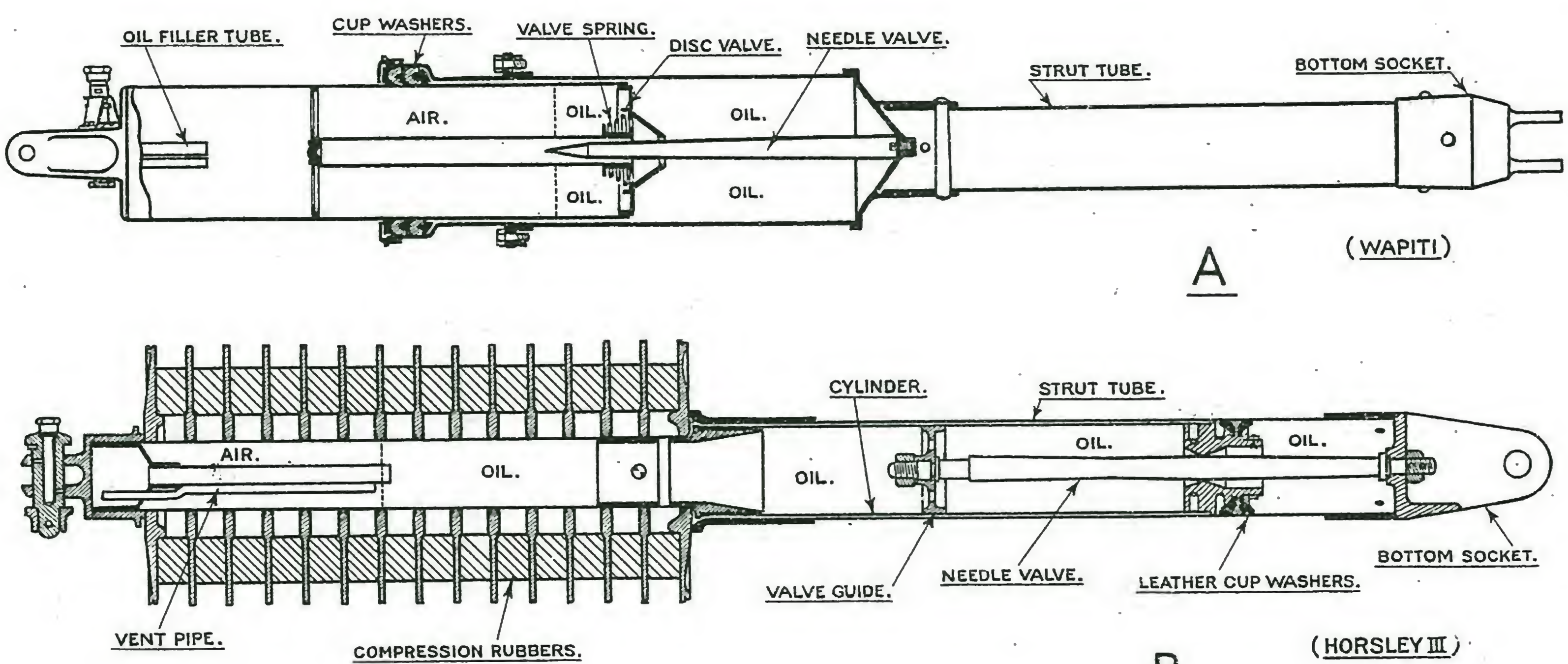

FIG. 69. OLEO LEGS.

P.9882.

202. Shock-absorbers for aircraft may take the form of rubber in tension or compression, or they may employ a steel spring or an oleo damping cylinder. Rubber in tension undoubtedly makes the lightest form of shock-absorber, but its behaviour under extreme climatic and atmospheric conditions precludes its use on modern service aircraft. Rubber in compression is also affected by like conditions, but with less serious results. Steel springs are usually durable, but generally they only reach their maximum efficiency at the one load at which they are designed to operate. Oil and air oleos can be made to operate efficiently over a large range of loading, and are to a large extent unaffected by climatic conditions.

203. An oleo leg of the type shown in fig. 69B has an oil dashpot which is used in conjunction with compression rubbers. In operation the oleo leg extends to its full length whilst the aircraft is in flight, due to the weight of the wheels and axle. Upon alighting, a compression load is applied to the leg which forces upward the lower sliding tube. By this action the oil is forced at high pressure through a restricted orifice, which delays the displacement of the oil, and consequently gives a comparatively gradual telescopic motion to the leg. If, after all the oil has escaped through the orifice, further compressive loads are applied to the leg, then the compression rubbers come into operation. Thus, the oil oleo operates only during the first actual landing contact, whilst the compression rubbers take any subsequent shocks, such as those due to taxying. When considering the shock absorption of an undercarriage, the effect of the large pneumatic tyres fitted to modern aircraft must not be ignored, as these are capable of absorbing all light shocks and a considerable proportion of the heavier ones.

204. The oleo shown in fig. 69A is similar in principle to that shown in fig. 69B, but it has an air cylinder instead of the compression rubbers. In this type of oleo the air in the cylinder has to be maintained at a pressure, varying with the type, of between approximately, 150 to 500 lb. per square inch. In operation the oil is forced through a variable orifice from the lower to the upper chamber, thus absorbing the landing shocks, and the air provides a cushioning effect when a subsequent load is applied, such as that due to taxying. For this type of oleo leg, special forms of hand air pumps are provided, Stores Ref. 4/257 and 27A/480. The maintenance and adjustment of the various types of oleo legs is fully dealt with in the aircraft handbooks and A.M.T.O's.

Metal tail-skids.

205. Metal tail-skids are very similar in action to those used on wooden aircraft, but the adaption of an all-metal

construction usually allows greater facilities and therefore the types vary to a greater extent. Fig. 70A indicates a typical tail-skid using rubber in compression, fig. 70B shows a type employing a steel spring, and fig. 70C a type utilising an air oleo.

Metal Airscrews.

206. Metal airscrews of two types are at present in service, the solid duralumin twisted sheet type and the hollow mild steel variety which is adjustable in pitch. The former is made from thick duralumin sheets and after being milled to shape the blades are twisted to give the required pitch. The bosses are constructed in two halves of either wood or metal; if the former laminated oak is used, if the latter then hollow aluminium castings are employed. In both cases the two halves are bolted to the blades.

207. The steel airscrew consists of a central hub which is provided with sockets, into which the detachable blades are fitted and clamped. The hollow blades are built up from laminations which are pressed into shape in a die, and edge-welded. There are generally four laminations, the innermost being shortest and the remainder increasing in length until the outside sheet forms the complete blade shape. The blades are welded to cyclindrical butts, which are machined to suit the sockets on the hub. The blades can be adjusted to give any pitch desired; the method to be adopted and the angular setting for certain aircraft is described in Air Ministry Technical Order 128 of 1927.

208. The light alloy airscrews have identification marks similar to those of wooden airscrews, but, for the detachable-bladed steel airscrews, the blades and the hubs are all given identification marks again similar to those described for wooden airscrews, but with the exception that the pitch and the name and series of engine are omitted. The protective covering of the light-allow airscrews usually consists of varnish, whilst the steel airscrew blades are stove enamelled.

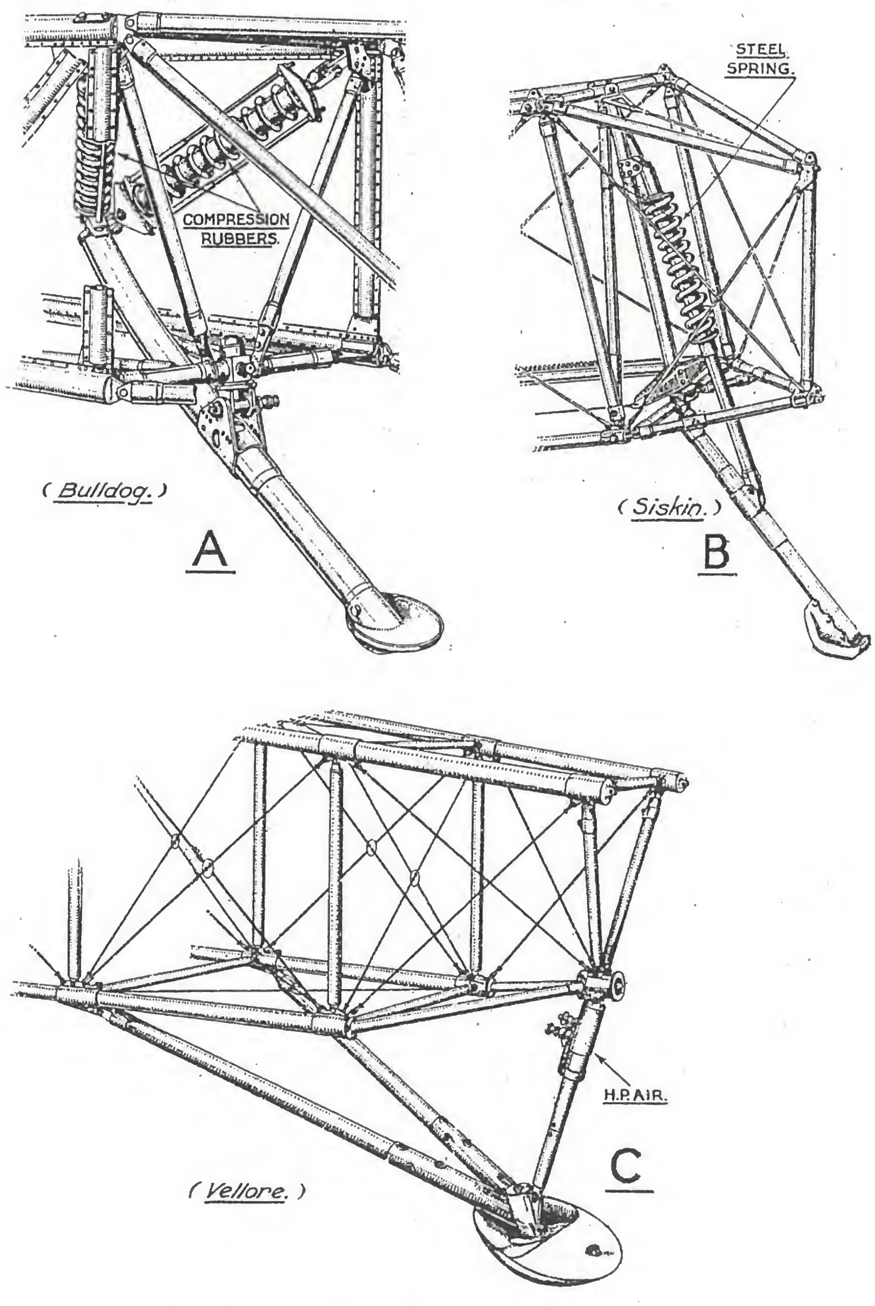

FIG. 70. METAL TAIL SKIDS.


B
A
C

CHAPTER VII.

ASSEMBLING AND TRUING OF A STRIPPED FUSELAGE.

Fuselage Assembling.

209. In the design of modern all-metal aircraft for service use, where the general and performance requirements are constantly increasing, there is of necessity a strong tendency towards making the fuselages rigid structures, using fixed-ended struts and very few or no bracing wires. The actual form of any fuselage structure varies with each aircraft in accordance with the general arrangement and design, but it is not uncommon for single-engined tractor aeroplanes to have the fuselage divided into three sections, the engine mounting as fore part, the middle section, in which is placed the pilot's cockpit and to which are attached the flying and alighting structures, and the tail portion which extends back to the fin and rudder post, and carries the tail unit and skid. Each part may differ somewhat in construction.

210. The types of construction may take either of two forms, monocoque as shown at figs. 42 and 61, or braced girder, as indicated in figs. 40, 43, 59 and 60. In the former, the skin takes the major portion of the loads from the tail and requires no rigging adjustments. In the latter, the struts and ties are placed in certain fixed positions, each taking its own definite load, and may or may not require truing up after assembly, depending upon type of design. The types of braced girders used for aircraft fuselages are the "N" which has vertical posts and diagonal struts, the double "N" or "Pratt," with vertical posts and cross bracing ties, and the "Warren" or inclined struts only. These types are indicated in fig. 71.

211. In the assembling of modern fuselages it is often necessary to have jigs in which to build up certain sections. The part so treated is generally the middle section, as this part is in most cases of very solid construction, often embodying the lower plane centre section spars, the attachments for the undercarriage and top centre section struts, and a considerable number of internal and external fittings. A middle section of a fuselage which is jig built should be correct to fine limits in every important detail, because all the various parts are usually secured together with a fixed relationship to one another, and form the basis on which the remainder of the structure is erected. In some forms of fuselage, notably the fixed-ended strut type, it is not unusual for the complete side frame to be built up in a jig, and then assembled together by the insertion of cross struts and transverse bracing wires or struts. In other types, particularly the larger kinds, the fuselage is built up

in two or more complete sections which are subsequently bolted together at the longerons.

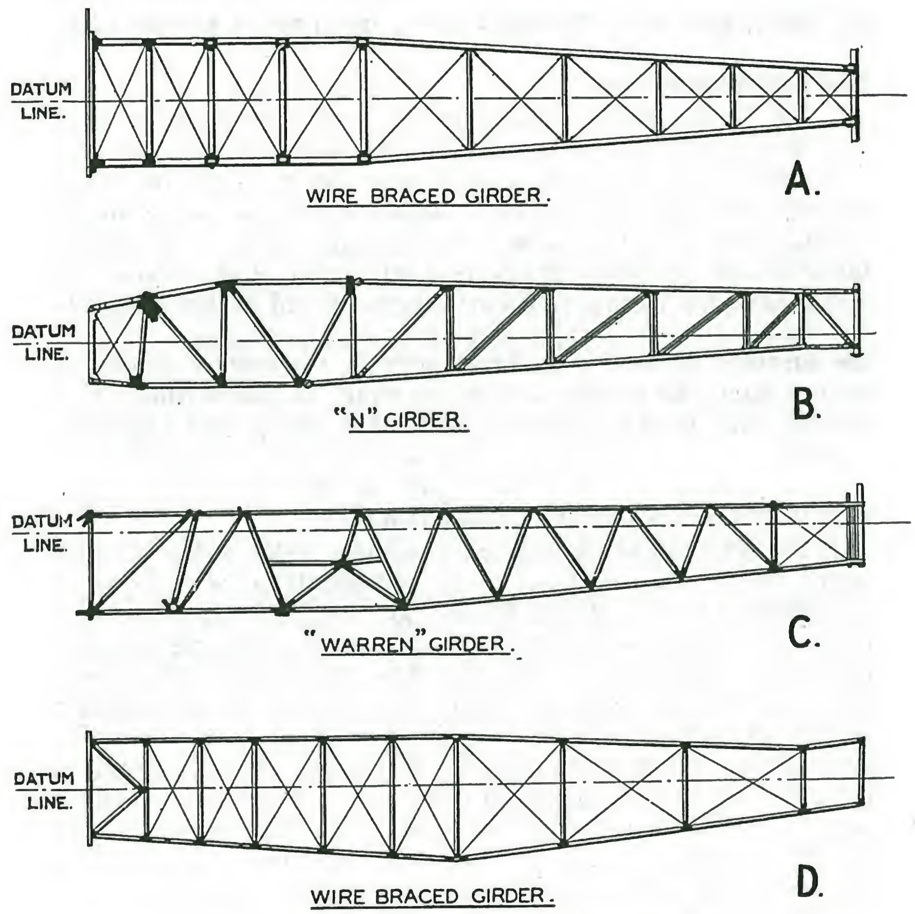

FIG. 71.—Types of braced fuselages.

212. With the fixed-ended strut types of fuselage, that is the " N " or " Warren " varieties shown at B and C, fig. 71, it is not possible to make many adjustments when rigging, because all the struts and component parts have been made and built up together in jigs in the first place, and therefore little more than correct assembling is required to obtain true alignment. Obviously, the amount of rigging needed depends upon the number of bracing struts employed. The more numerous the diagonal struts are, the less will be the rigging required.

Fuselage truing.

213. In those cases where it is merely required to check the truth of the fuselage of an aeroplane, the coverings and fairings are detached as found necessary, and the fuselage

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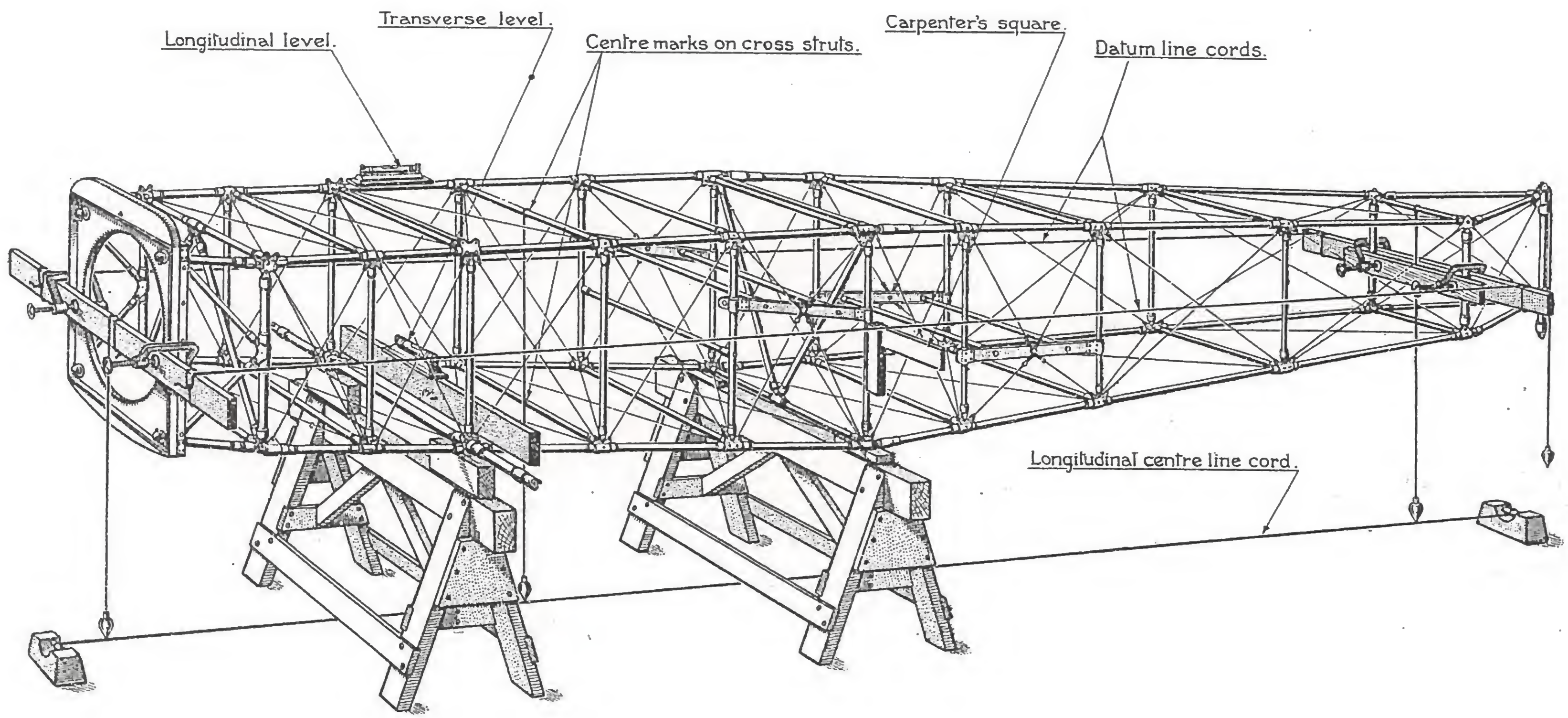

FIG. 72. TRUING A FUSELAGE.

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arranged on trestles, or suitably jacked up, until the datum line is horizontal and until it is also transversely horizontal, as ascertained by placing spirit levels on the longitudinal and transverse levelling plates. If levelling plates are not provided, then spirit levels are placed on those parts of the top longerons which are parallel with the datum line, and also on straightedges placed across the fuselage. Two straightedges are then laid across the longerons, one as far forward as possible and the other positioned at a number of different points in turn, and the top edges are viewed from the front or rear to check for parallelism. Unless trammels can be effectively used, it is difficult to check properly the side frames in a completed airframe, but the method of checking by straightedges given above will show if one side is out compared with the other. During all checking operations it is essential that the bracing wires should be at the correct tension, as described in para. 222.

214. Before a fuselage can be trued up, it is usually essential to know the position of the horizontal datum line, that is, the line in side elevation of the fuselage which will cut the side struts at certain known points. Generally, this line will be made horizontal when the fuselage is placed in rigging position. It is sometimes found that the situation of this line is marked on the side struts of the fuselage frame during manufacture, or levelling plates or pegs are provided for the same purpose. If no indications are given on the structure, it is important that the drawings of the fuselage or the handbook should be consulted before definitely adopting any position for the datum line.

215. The most difficult form of fuselage to true up is that of the double "N," shown at A and D, fig. 71, where pin-jointed struts are used in conjunction with diagonal cross bracing wires; the following description of the method of truing up a fuselage deals with this type. The procedure outlined is intended as a guide only, and is not identical with the methods adopted for all similar types of fuselage. It will not be always possible to make all the adjustments enumerated, the tendency being for the correct rigging of a fuselage to become more and more a matter of assembly. For particular aircraft, reference should be made to the aircraft handbooks where mention is made of the normal methods to be used for the type. The form of the typical body generally agrees with one of the shapes shown in fig. 71, that is where the fuselage is symmetrical in side view as at A, or where the top longerons are horizontal as at C, or partly so as at B and D.

216. In the following paragraphs the truing up of a fuselage which has been entirely dismantled and reassembled is described, but partial truing up would be carried out on the same lines. The amount of truing up to be done, and the extent

to which the fuselage must be dismantled, would depend upon the degree of distortion, or the extent of the repair or replacement, if such has been effected.

217. The general method of truing up a fuselage of the type shown at D, fig. 71, is first roughly to true up the structure, then set up the fuselage accurately on the trestles, and complete the truing. The procedure is as follows :—

(i) As shown in fig. 72, the fuselage is supported on two trestles, at points which have been pre-determined by the provision of jacking pads, or in the positions given in the handbook. Except in those cases where the top longeron acts in this capacity, the datum line must be marked off and cords stretched along at datum line height on each side of the fuselage parallel with the side frames.*

(ii) To do this, select suitable transverse panels at the front and rear, and true up by adjusting the cross bracing wires until the diagonal distances are equal, as determined by measurement or by using trammels. If an engine plate acts as the front panel, this can be used, and will, of course, require no truing up. The front pair of struts, or engine mounting plate, and also the rear pair of struts, are then marked off at the heights which are given as representing the datum line, and straightedges clamped on in the manner shown in fig. 72 with their top edges at exactly the same height as the marks. One or more of the centre struts on each side of the fuselage, (strut No. 7 in the instance given in fig. 72) are also marked at the height given for the datum line. Cords, or threads, are then tied to the straightedges and stretched tightly over them, so that the under surface of the cords is on a level with the marks on the front and rear struts. The cords must not touch the side of the fuselage, nor have any perceptible sag.

(iii) The next operation is to true up the transverse panels, by adjusting the wires until both diagonals are of equal length, and check with trammels.

(iv) The top and bottom bracings should then be treated in a similar way, checking the diagonal bracings with trammels as before, and adjusting the wires as necessary.

(v) The next procedure is to true up the fuselage side frames roughly by holding a carpenter's square against one of the marked centre side struts, and making adjustments to the diagonal bracing wires until, when the blade of the square just touches a cord, it also touches the mark

* The use of No. 18 white thread, Stores Ref. No. 32/B/451 is recommended.

on the strut. The longerons must not be allowed to sag or bow during these adjustments, and occasional visual checks must be made by sighting along the straight portions. It is essential, when adjusting wires, that the rigger does not attempt to pull the structure true by tightening the wires only. If an adjustment has to be made, the impeding wires must first be slackened off before adjusting the selected wire.

(vi) After this, the fuselage will be roughly true, and the final work of checking and making small adjustments may be proceeded with. To do this the front and rear trestles should be adjusted until the fuselage is longitudinally and transversely horizontal. If fixed trestles are being used, the adjustments for height should be made with wooden packing pieces. The longitudinal level of the fuselage can be checked by resting a spirit level on any part, such as the front portion of the longerons, which is parallel to the datum line, and the transverse level by laying a straightedge and spirit level across the fuselage at right angles to its plan centre line at a number of different points. The side cords must be left in position, as a check will be required if any adjustments are made to any transverse upper or lower panels, owing to the possibility of subsequent adjustments upsetting those already made.

(vii) The middle points of all upper and lower cross struts are then marked, midway between the inner faces of the longerons, and a plumbline tied to the front upper strut, or engine mounting plate, at the marked point, and to the rear cross strut also at the marked point. Next tie the ends of a cord to heavy weights, or over trestles, and arrange the cord underneath the centre line of the fuselage, so that, when tightly stretched, it is just clear of both plumb-bobs.

(viii) Now hold or tie a plumbline to each upper cross strut in turn, and adjust the bracing until the plumbline touches the marked middle points of the corresponding upper and lower cross struts, and the plumb-bob is directly over the line stretched beneath the fuselage.

(ix) Check the side frames as outlined in (iv) and make any necessary adjustments.

(x) The rigger should finally test each bracing wire to see that all are properly locked and are at the correct tension. (See para. 222.)

218. If the fuselage possesses a stern post, or it is possible to erect one temporarily, it is advisable to check continually the truth of the stern post with a plumbline during the truing

up operations. It is of assistance in many cases to check by sighting that the upper surfaces of two straightedges, placed across the top and bottom longerons at various positions, are parallel. When the checks enumerated have been satisfied, the fuselage may be considered fully trued up.

219. When adjusting the wires of the side, top, and bottom frames, it should be remembered that these are interconnected with the wires of the transverse panels, and must, therefore, all be "kept going" together. As an instance, when adjusting the side bays to bring the side strut datum line marks into alignment, the transverse cross bracing must also be adjusted, and checked by trammelling. In addition, the other side of the fuselage will probably need adjustment. Otherwise it would be possible to true one side until it was true as a whole, but after truing the transverse panels it would probably be found that the side was out of truth again.

220. A fuselage of the type shown at A, fig. 71, can be trued up on the same principle as the one already described, but is somewhat simpler, as greater use can be made of trammels in the initial rough truing up and subsequent checking, because the diagonal cross bracing wires in the side frames are of equal length when correctly rigged. Also datum line marks can be made on all struts, as this point is situated at the centres of their lengths.

221. If the fuselage is of the shape shown at C, fig. 71, but has cross bracing wires instead of diagonal struts, the procedure given can be applied, but as the longerons are straight and are horizontal when the fuselage is in rigging position, they may be used instead of the side cords for the truing up of the side frames.

Bracing wires and attachments.

222. Before a fuselage is left, all the bracing wires must be as near the correct tension as possible. Various instruments have been devised to measure the tension of wires, but few are actually in use, and it is seldom that the rigger has anything except his own judgment to guide him. The cultivation of this judgment is largely a matter of experience, and riggers should lose no opportunity of testing the tautness of wires that are passed by experienced men as correct in tension. It is important that the wire should not be too tight, as this naturally places an initial stress on compression members, and may even bend them. On the other hand, a wire that is too slack will, when under load, fail to perform its proper function, and may throw extra stress on other parts of the structure. As a general guide it can be assumed that all wires are sufficiently tight if, after the slack has been taken up, they are

given from half to one turn, depending upon the size and length of wire, and the solidity of the surrounding structure.

223. With streamline wires it is not possible to turn the wire less than half a turn; therefore if a quarter-turn is required, the wire is slackened off and the pin extracted from one of the fork ends, which is then detached from the wiring lug. The fork end which has been detached is then rotated on the wire half a turn and replaced on the lug. Referring to fig. 73, it must be noted that the screw threads on the ends of

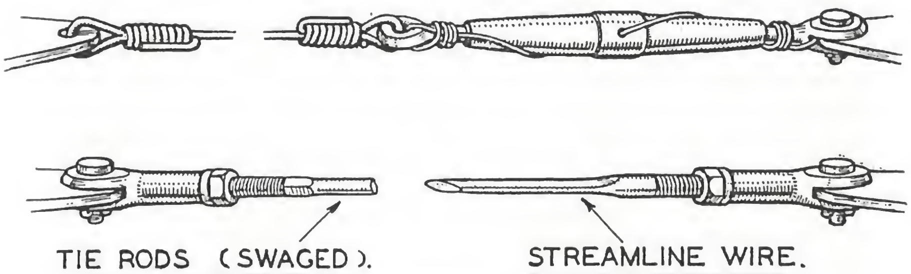

FIG. 73.—Bracing wire attachments.

the wires, either streamline or the circular-section swaged tie rod, are cut right- and left-handed, so that in rotating the wire one turn it has shortened the distance between the pin centres by the equivalent of not one thread, but two. It must also be noted that the locking nuts are made of soft material, either brass or cast iron. The object of this is to prevent any stripping of threads or over stressing of the wires when tightening the locknuts.

224. A fork end invariably has a small hole drilled about half-way along the barrel. The distance which this hole is from the end of the barrel is equivalent to the minimum amount of thread which should be in engagement, and is placed in this position to allow the point of a scriber or a small piece of wire to be inserted as a feeler.

225. It is of great assistance sometimes, especially during the repair of a fuselage, to use some form of temporary bracing. This is usually arranged with piano wire and turnbuckles, shown in fig. 73, which are attached to specially prepared wrapper plates or clips fitted round the parts to be braced. If turnbuckles are used on the permanent structure, they are locked with soft iron wire in the manner shown.

226. All split pins used must be of correct size and length, and well spread and turned over. A split pin must on no account be used a second time. If it is necessary to detach a split pin when dismantling, it must be thrown away and a new one used upon re-assembly.

CHAPTER VIII.

ASSEMBLING AND TRUING AND COVERING OF PLANES, CONTROL SURFACES, AND UNDERCARRIAGES.

Assembling of planes.

227. Initially, most manufacturers assemble the component parts of a wing together in jigs. This method ensures that the planes are true when completed, and that like parts are interchangeable. With the wooden types, where the various parts of the structure are glued and screwed or bradded together, it is not an easy matter to dismantle wings for reconditioning or other purposes without doing considerable damage to parts which it may be desirable to preserve. Generally, the complete dismantling and re-assembling of wooden wings is undertaken by the manufacturer, and, even under these conditions, only a few parts, such as the metal fittings and occasionally a spar, are salvaged from a wing which is unserviceable to the extent warranting reconditioning. Where the reconditioning of wings is undertaken by the service, the structures are usually re-built in accordance with the drawings provided for the purpose.

228. With metal construction, on the other hand, there is a possibility, if great care is exercised, of partly or completely dismantling a wing with little or no damage to the various parts, but this work is usually done at depots or at the manufacturer's works, where the special sections, component parts, drawings and jigs are available. The necessary repairs of a minor nature which are undertaken by service units are carried out in accordance with the repair scheme which is issued officially for each type of aircraft.

229. In the assembling of a metal wing, the ribs are usually threaded on to the spars and placed in their approximate positions before the drag struts and cross bracing wires are fitted. The ribs are then attached in their definite positions, and the leading and trailing edges assembled in the manner suited to the type of design.

Fabric covering.

230. The re-covering of a wing with fabric is an important item in the reconditioning or repair, and the methods employed must be strictly in accordance with the official instructions on the matter, and, unless instructions are issued to the contrary, will be in accordance with the standard methods described below. The fabric covering normally used for planes is of

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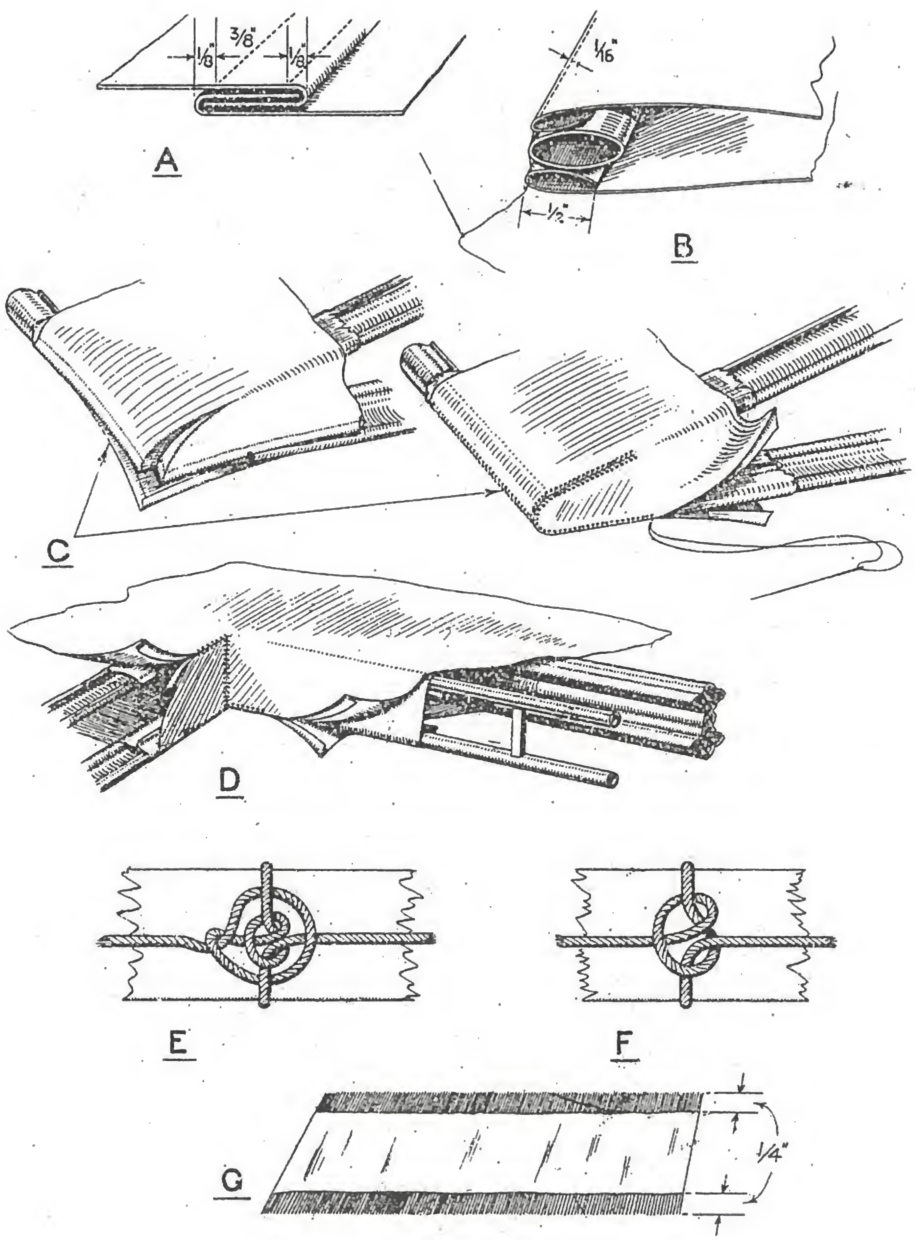

FIG. 74. FABRIC ATTACHMENT BY SEWING.

the best quality linen to B.E.S.A. Specification 4F.1, Stores Ref. 32B/147. The fabric is usually attached to the planes by sewing with braided cord to B.E.S.A. Specification 2F.25, Section II, Stores Ref. 32A/94.

231. The types of seams used when covering planes are shown at A and B, fig. 74. The seam shown at A is the double balloon seam, and should be made as indicated. The seam at B is used to tighten the fabric at the trailing edge and other parts, and is arranged so that the edges of both portions of the fabric are inturned to form folds of about $\frac{3}{8}$ in. to $\frac{1}{2}$ in. in depth, and are located parallel with the edge of the structure along which the seam is to be made. The lines of the seams should be from $\frac{3}{16}$ in. to $\frac{1}{4}$ in. distant from the edge to allow for pulling up. Hand-sewn seams are lockstitched approximately eight stitches per inch and double-lockstitched every 6 in., using single 18S or double 40S linen thread to B.E.S.A. Specification F.34, Stores Ref. 32B/451 and 32B/413 respectively. Machined seams should have approximately nine stitches per inch, using single 40S linen thread of similar specification. At C and D, fig. 74, are indicated the methods used for covering the corners formed at the trailing edge of the end ribs and in the aileron gap respectively. In the latter case it will be noted that the seams are made along the lower edge of the former parallel with the main spar, and at the upper edge of the end rib. The forward seams should always be sewn before the other seams are made.

232. Before the fabric is placed in position on the planes, all the corners where the fabric is likely to touch and chafe must have a strip of fabric doped, glued or sewn on. This applies also to the ribs and the leading and trailing edges. The linen or Egyptian tape which is used on wooden ribs, has normally a width sufficient to give an overlap at the edges of from $\frac{1}{4}$ in. to $\frac{3}{8}$ in. and is attached by a line of glue down the centre of each rib flange. The tape is usually sewn to metal ribs by the methods indicated at A, fig. 75. After the preliminary taping has been accomplished, the fabric is secured to the framework of the plane by sewing or stringing to the ribs with the braided cord (which is waxed to prevent slackening), as shown at A, fig. 75. The usual pitch of stitches is 3 in., and the knots are made on the upper surface of the plane at each stitch. The stitching is double-knotted at approximately every 18 in. on the upper surface of each rib. At E, fig. 74, is illustrated the method of knotting the cord at the forward end of the rib, and also at the points at which it is double-knotted. All the intermediate single knots are made as indicated at F, and the sewing is finished off by the double knot shown at E.

233. In order to reinforce the fabric over the ribs and also to prevent it from tearing away from the stitching, linen webbing or Egyptian tape is laid on the fabric over each rib before sewing. The ends of the tapes may be temporarily secured by being tacked to the fabric. After the string sewing, the stitching is covered with the frayed-edge linen tape shown at G, fig. 74 ; this tape is doped in place after the first coat of dope has been applied to the plane. The leading edge, the upper and lower edges of the inner ribs and the members bounding the aileron gap, and all similar corners where the fabric is likely to be subjected to friction or hard usage should be covered externally with a strip of fabric doped on. Where plywood is used as a reinforcement to the fabric, or to give the correct contour in such positions as the nose of the plane, it may not be necessary to adopt the method of stringing given above, provided the fabric is properly attached to the plywood by doping. When this method of attachment is used at the nose of the plane, the upper fabric must be frayed at the edge and taken well round the nose, and must overlap the lower fabric by some inches.

234. In those aeroplanes which are fitted with engines of over 400 H.P., special precautions must be taken with the fabric in the region of the airscrew slipstream. Considerable trouble has been, and is still being experienced with the fabric attachment in this position, due no doubt to the rapidly fluctuating pressures imparted by the airscrew slipstream. The normal method of attachment in these positions is to halve the pitch of the stitches, making them every $1\frac{1}{2}$ in. instead of 3 in. This method will give satisfaction for a reasonable period, but it is most important that the rigger should very carefully examine the fabric attachment of any planes in the region subjected to the slipstream. It is not sufficient merely to ascertain that the fabric has a satisfactory appearance ; investigations must be made to ensure that the stitching cord has not become frayed or chafed inside the plane.

235. Some variations of the method of attachment given above are allowed for certain aircraft. On those rib booms which present a sufficiently rounded surface, the stringing is arranged round the boom as shown at B, fig. 75, instead of being taken right through the plane. This method is particularly adaptable for deep wing sections. Another method is to thread a metal wire through the tape and the fabric and also through eyelets, or bridge pieces, formed in the rib booms, as indicated at C, fig. 75.

236. It is not always essential to tape the ribs under as well as over the fabric covering ; the tape on top of the covering is all that is necessary if the rib presents a sufficiently

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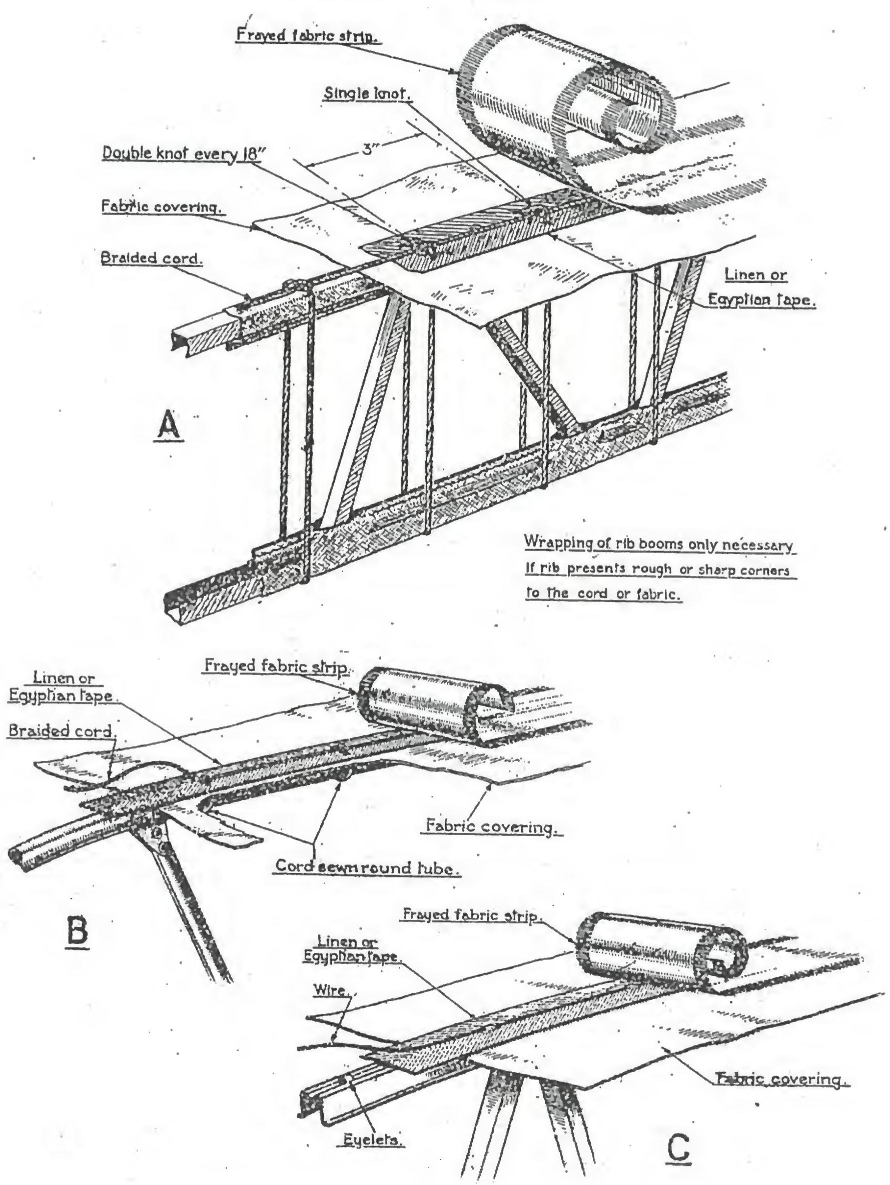

FIG. 75. FABRIC ATTACHMENTS TO RIBS.

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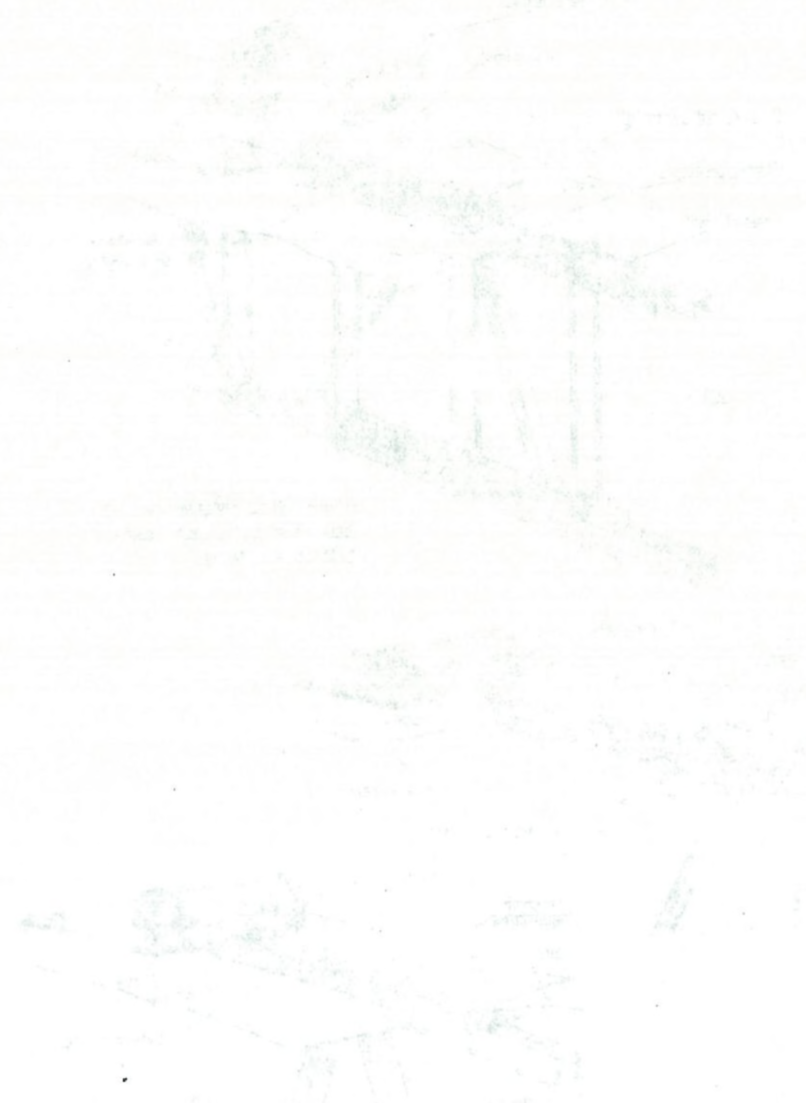

smooth surface. When re-covering wings, care should be taken to adopt exactly the method of attachment approved for the type of aircraft, as is ascertained when stripping down the wing.

237. Before being used, fabric should be stored for as long as possible at a fairly high temperature, 73° F. being suitable. This will thoroughly evaporate all moisture which would prevent satisfactory doping. Before gluing fabric on to wood, the fabric should always be thoroughly washed, as otherwise the presence of the dressing substance in the linen makes it difficult to obtain good results. Where the fabric is attached to wood and has to be subsequently doped, glue is not, as a rule, used as an adhesive, as not only is there a danger of the fabric rotting, but the glue has a detrimental effect on the applied dope. In these circumstances, dope is the best adhesive, and for smoothing down, wads of doped fabric should be used. After the wing covering is completed, the fabric is given several coats of dope, the final coats being pigmented, that is, with a colouring matter added.

238. It is important that no aircraft should be flown with openings in the wing covering, other than those designed to be there, as the effect may be to alter the static pressure within the wing to such an extent that the normal rib loading is considerably exceeded.

Truing up of planes.

239. The truing up of planes after re-assembly or repair is a comparatively simple matter and is similar for either wood or metal structures. The framework of the normal form of plane is similar to that illustrated in figs. 32 and 52, and described in paras. 139 and 180, and as will be seen, consists of two spars, generally parallel, which are the main strength members and which are braced together by the usual form of lattice bracing; that is, the spars are separated by drift struts and the open panels formed by the spars and the struts are cross braced with the usual form of tie rods, the strength of which gradually decreases from the wing root to the tip. The remaining parts, such as the ribs and the leading and trailing edges, act as formers, and are provided to give the shape of the wing, and to transfer the air loads from the fabric on to the main strength members.

240. To true up the planes, lay the structure across two trestles, placing packing blocks on the tops of the trestles so that the weaker parts of the plane are clear of the trestles, and, commencing at the wing root, adjust the diagonal bracing until trammelling indicates that the diagonal distances are equal in each bay. The planes of a biplane are usually thin

compared with their length and breadth, and will in most cases deflect considerably if inadequately or incorrectly supported. Care should therefore be taken to ensure that the structure is securely supported and that the spars are at the same level. When the bays are small, minor inaccuracies are hard to detect ; therefore, it is advisable to mark off equal distances, say 5 ft., along each spar from similar points on the root fittings and trammel the diagonal distances between the points marked and the fittings, and adjust the bracings until these distances are equal. When completed, the plane should be checked by taking diagonal measurements from the outer end of each spar to the root fittings on the opposite spar, and each spar should be checked for bowing by using a long straightedge or a tightly stretched cord.

241. When the plane has sweepback, and consequently the end rib at the root of the plane is not at right angles with the spars, the method outlined cannot always be employed. When the plane is so constructed that, with the exception of the strut between the spar root fittings, the drift struts are placed at right angles to the spars, the end bay may be ignored for truing up purposes and the procedure for truing up is then similar to that already given. When the drift struts are all parallel to the line of flight and therefore not at right angles with the spars, the truth of the plane must be judged by the angular displacement of the front spar root fitting in relation to the rear spar root fitting. Taking a line through similar points on the spar root fittings, the bracings are adjusted until the angle formed by this line and a line taken at right angles to the rear spar, from the same point on the rear spar fitting, is equal to the angular sweepback on the planes.

Truing up control surfaces.

242. The truing up of tail planes follows the general lines laid down for the truing up of the main planes, special attention being paid to the lining up of the hinge points. Normally, elevators, ailerons, fins and rudders cannot be trued up in the ordinary way, as these components are usually rigidly built. Therefore, if these parts become seriously out of truth, then replacement or repair will be necessary.

243. Before passing any main plane or control surface as ready for re-covering, it is necessary that a very thorough inspection should be made to ensure that the structure is in a safe and serviceable condition, that all wires are locked, and that no fatigue failures, actual or incipient, are evident, and that no chafing of the wires or other parts through vibration is possible.

Truing up of undercarriages.

244. Undercarriages vary in design and construction, but are as a rule fairly simple to rig correctly provided the component parts are properly assembled. In all cases undercarriages should be, as far as possible, assembled on the floor and then lifted into position.

245. Undercarriages are invariably rigged so as to be symmetrical about the centre line of the fuselage in front and plan views. In the assembling of the undercarriage to the fuselage, the first problem to be met is the supporting of the fuselage at the correct height. When preparing the fuselage for the reception of the undercarriage, it should be jacked up into rigging position, allowing sufficient room for the wheels to be free of the floor when the undercarriage is fitted. Jacking pads are usually provided for this purpose on the underside of the fuselage, but if pads are not actually provided, there is usually a point indicated as that correct for jacking up. Should no indication be given, choose a position on a fitting as close up to the front undercarriage strut attachments as is convenient. If an adjustable trestle is not available and ordinary jacks are used on trestles, then care must be taken that the heads of the jacks do not damage the fittings or structure. A way can always be found of supporting the fuselage without placing undue stress on the fuselage or engine mounting, and, where special equipment is necessary, it is as a rule available to the unit. If it becomes essential, it is always possible to improvise safe methods, provided attention is paid to the fuselage construction and to the design of the undercarriage, so that the supports may be well clear of the landing gear during the necessary assembling operations.

246. The type of undercarriage commonly in use for the smaller aeroplanes is shown in fig. 67 and consists in side view of two struts forming a V, the top ends of the struts being attached to the fuselage and the lower ends connected together with a universal joint at the axle. One of these struts usually incorporates some form of shock absorber and is telescopic, and the other acts as a radius rod. In front view, an undercarriage of this type is usually cross braced, with flexible cables, in the panel formed by the radius rods. The truing up of this type of undercarriage is done in a similar manner to that described in para. 248 below.

247. Where a split axle undercarriage is used, similar to that shown in fig. 68, no rigging will be required, as all the parts are made to a fixed length and correct assembly should ensure a symmetrical undercarriage. If a check for alignment is required for this type of undercarriage, it should be carried out as for a wire-braced undercarriage. If, as a result of the

check, it is found to be out of alignment, then all fittings should be carefully examined and a comparative check made between the pin centres of all corresponding members, and the damaged or faulty part removed and substituted by a new part.

248. When a type of undercarriage similar to that shown in fig. 76 has to be trued up, the cross bracing shown at BB and CC should be adjusted to be equal in length, checking by trammel. The undercarriage should then be true, but to verify, drop plumb lines from the fuselage lower longerons on to the centre lines of the axle tubing, and measure along

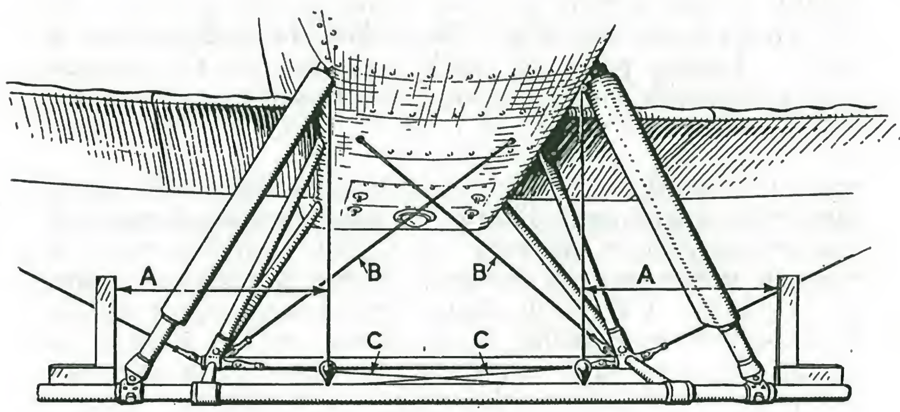

FIG. 76.—Truing an undercarriage.

the axle from these points to the inner flanges at the wheel hubs, A and A in fig. 76. When the axle is central with the fuselage, the distances will be equal on each side. A check for symmetrical rigging in plan view can be made by comparing the distances from the axle extremities to some fixed point on the centre line of the aeroplane near the sternpost.

249. Rigging adjustments to an undercarriage must be made with the aeroplane jacked up so that the weight is taken off the wheels. In this way, errors due to inequalities in the lengths of the shock absorber legs are obviated, as is also the danger of the undercarriage collapsing sideways should one of the wires become detached accidentally.

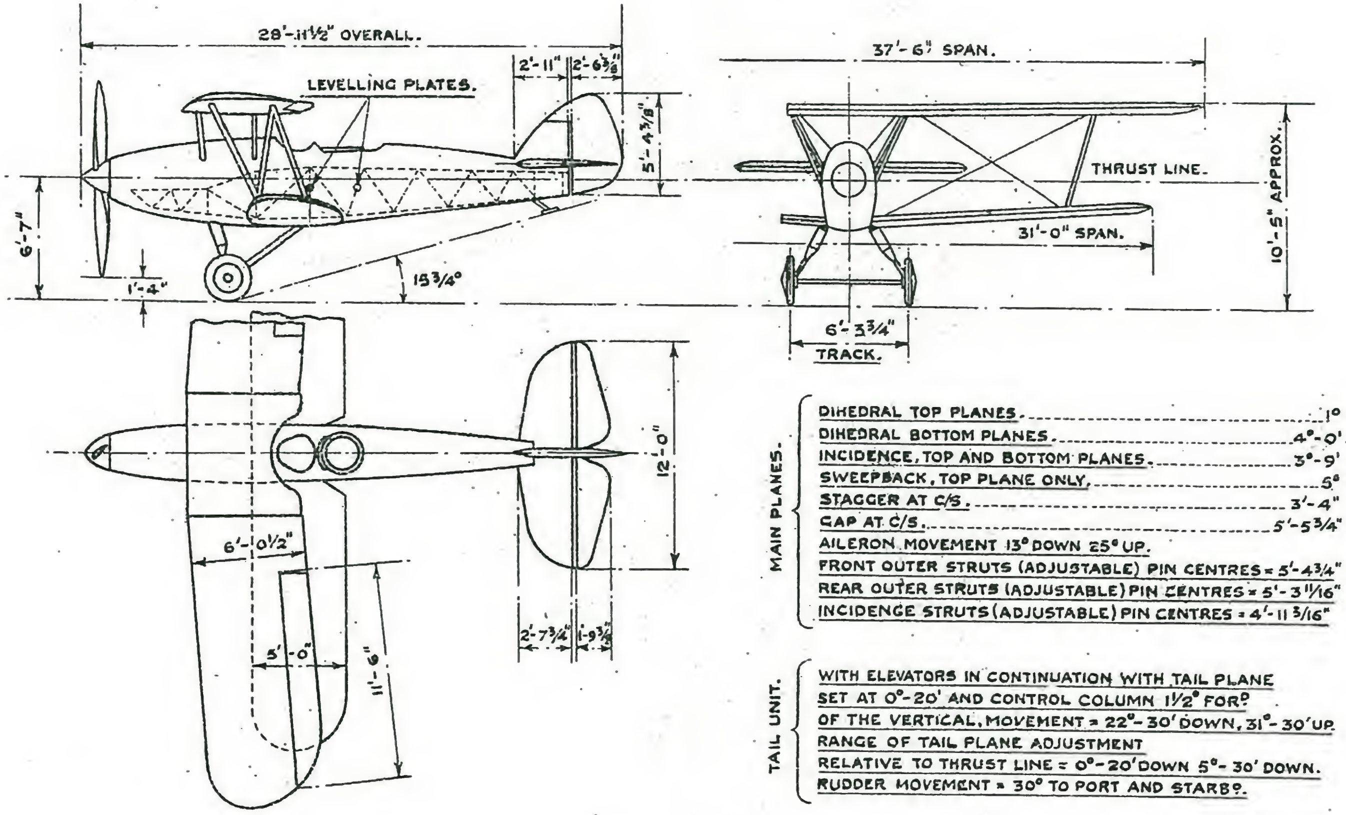

FIG. 77. TYPICAL RIGGING DIAGRAM.

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CHAPTER IX.

ASSEMBLING AND TRUING UP A COMPLETE TRACTOR BIPLANE.

250. It is very difficult to lay down a definite procedure for the assembly and truing up of complete air-frames which would cover all types, as each particular type has usually some peculiarity of its own. The instances and methods given below should provide sufficient information to act as a guide for all types normally encountered.

251. An airframe is usually issued in components, that is, a complete fuselage, a complete undercarriage (which for the smaller aeroplanes is usually attached to the fuselage), centre sections, upper and lower, port and starboard main planes, tail plane or planes, ailerons, elevators, fin and rudder. To facilitate transport, some of the larger types of aeroplanes have the fuselage and also the main planes built in two or three sections, but in the following descriptions the components are considered as a whole, as the assembling of these parts is peculiar to the type, and for any necessary instructions regarding these parts reference should be made to the handbook of the type.

252. The difference between the assembling and truing up of a wooden airframe and that of a corresponding all-metal structure is usually not very great, but, as a general rule, the assembly of the latter type is somewhat easier than that of the former. This is owing to the fact that the interplane struts and other parts are made to a jig, and should therefore require little or no fitting, and also that struts, both fixed and pin-jointed, are used to a greater extent for bracing purposes.

253. A rigger is generally given all the particulars required when dealing with a particular type of aeroplane. Fig. 77 shows in diagrammatic form the information normally supplied. In addition to this, it is usual to provide any special information or warnings regarding the assembly, rigging or maintenance peculiar to the type.

Setting up the fuselage.

254. The first component to be handled in the assembly of an airframe is the fuselage, and it is assumed here that it is correctly rigged. If there is any doubt about the correctness of the rigging of a fuselage it should be checked as enumerated in Chapter VII. The fuselage should be placed on trestles, and arranged longitudinally and transversely level. If the undercarriage has not been attached, the height of the fuselage should be sufficient to allow the undercarriage to be placed in position.

255. The attitude of the fuselage, when correctly positioned for the assembly of the supporting and controlling surfaces, is termed the "rigging position," and is not necessarily the same as that used for the truing of the fuselage. The rigging position is usually clearly indicated in the rigging notes or the aeroplane handbooks. The provision on the aircraft for determining this position usually takes the form of a horizontal line painted on the side of the fuselage or levelling blocks or plates are attached to the members, so that the rigger may know that the fuselage is in rigging position longitudinally when a line taken through these points is horizontal. If clear instructions are not given for finding the rigging position, then the correct attitude for the fuselage can be obtained by arranging the fuselage so that the incidence of the lower centre section is at the correct angle. The transverse level can be ensured, if levelling blocks are not provided, by placing a spirit level on one of the fuselage cross members.

256. The method of supporting the fuselage varies to some degree, as the jacking points are in slightly different positions for each type of aeroplane. The jacking points are usually situated at, or forward of, the front undercarriage struts, and also at the rear of the fuselage in the neighbourhood of the tail skid. If adjustable trestles are available, the smaller types of fuselage can be jacked up directly at these points by placing the trestles across the underside of the fuselage as shown in fig. 79. If suitable adjustable trestles are not available, then the ordinary lifting jacks must be used, placed on fixed trestles or a similar form of rigid support. Packing blocks are often used when jacking up a fuselage, and care must be taken to ensure that the blocks are substantial and are securely positioned so that the weight is taken on the pads provided. If there are no clearly defined places for the supporting trestles, the greatest care should be taken in choosing these positions. It is always safe to place the front trestles at the front undercarriage strut fittings, as a strong bulkhead or strut is invariably placed in this position, and to choose a position for the rear trestle where the fuselage is strengthened to take the stresses due to the tail plane and tail skid.

257. If the fuselage has the undercarriage already attached it is not necessary to raise the front of the fuselage very much, only sufficient to take the weight of the fuselage off the wheels. Occasionally, special jury struts are supplied by the manufacturers, or wooden blocks are suitably disposed, so that, when these parts are used, the oleo leg strut is given a fixed length. In these circumstances, it is possible to raise the front part of the fuselage into the rigging position by jacking up the undercarriage only. If some form of jury strut is not

employed, it is obvious that, owing to the shock-absorbers, the undercarriage alone will not provide a sufficiently steady support for rigging purposes.

258. The normal method of levelling a fuselage or an airframe is first to level the fuselage longitudinally, and when this is roughly correct the transverse levelling is proceeded with. When the transverse levelling is correct, the longitudinal levelling is again checked, and any necessary adjustments made until the fuselage is securely supported and is level transversely and longitudinally.

Attaching undercarriage.

259. If the undercarriage is not already attached, this part should at this stage be fitted, and trued up as already described in paras. 244 to 249.

Attaching tail unit.

260. After the fuselage has been securely positioned in the rigging attitude, the tail planes, fin, and rudder can be fitted and roughly trued up, and the control cables or rods connected. The final truing up of the tail unit is better left to a later stage.

Attaching centre section.

261. The upper centre section is usually the next component to be erected. One method of doing this is to place the upper centre section plane upside-down on a piece of felt or similar material on the ground, and to fit the four centre section struts; the bracing wires should then be attached, and the whole unit lifted into position. The loose ends of the struts are next attached to their respective fittings on the fuselage, and the ends of the bracing wires or struts connected up.

Truing up centre section.

262. To true up the centre section, trammel the front and rear diagonals until the leading edge of the upper centre section plane is horizontal, and is symmetrical about the vertical centre line of the aeroplane. If the planes possess any degree of stagger, and this is not fixed by side bracing struts, the side cross bracing wires must be adjusted until this is correct.

263. Cross bracing wires must never be used to pull a plane into its correct position or incidence. In all cases impeding wires must be definitely slackened off and the plane moved, or allowed to move sufficiently, and then the wires re-tightened.

264. The method of checking is as follows :—Drop plumb-lines from the extremities of the top front and rear centre section spar end fittings, as shown in fig. 78, and measure the gaps "A" and "B," which should be the same on each side

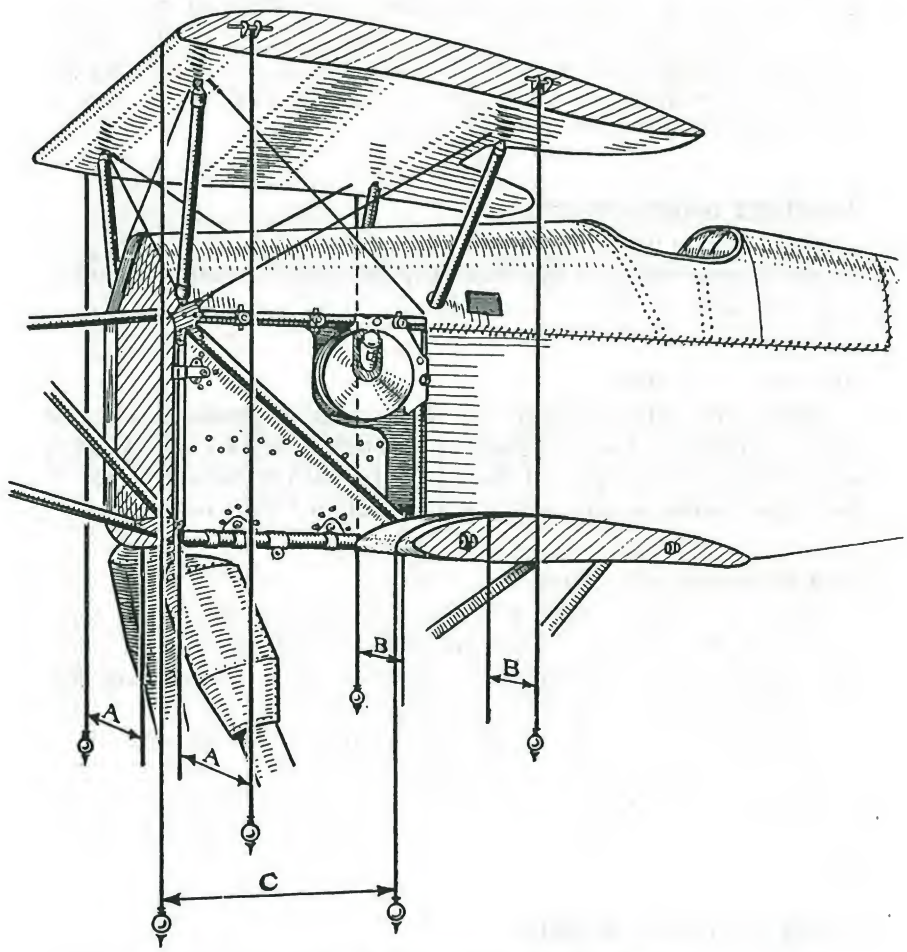

FIG. 78.—Truing a top centre section.

of the fuselage. To check the stagger, drop plumblines over the leading edge and measure the distance "C." This should also be the same on both sides, and should be in accordance with the instructions issued.

265. In some cases there will not be a separate top centre section, but the roots of the top main planes will meet at a point over the centre line of the fuselage. In this event, there will be some form of pylon or triangulated strut formation over the fuselage for the attachment of the planes. After this

has been erected it can be checked by dropping plumblines from the centre of the top fittings, and measuring from the plumblines to each side of the fuselage fittings. These distances should be equal. Sighting from the front across the two plumblines towards the fin post will prove whether the fittings are in alignment with the fuselage centre line.

Attaching main planes.

266. There are two commonly used methods of mounting the main planes on the fuselage, the choice between these two methods being decided chiefly by the size, weight, and design of these components.

267. In the first method, which is more applicable to the smaller types of aeroplanes fitted with two sets of struts, one of the lower main planes is placed with its chord vertical, and the leading edge resting on some protective material on the ground. The protective material is required to prevent injury to the leading edge, and should consist of felt placed in shallow wooden troughs. The interplane struts should next be fitted to their respective attachments, and the upper main plane brought into its proper position in relation to the lower, so that the interplane struts can be attached to this plane also. The bracing wires, which are supplied in their correct lengths and identifiable by tags, should then be joined to their respective fork ends (taking care that the same number of threads on each end of the wire are in engagement) and attached to the wiring lugs. In this way the complete cellule of the planes for one side will have been boxed up into a fairly rigid structure, which can be easily handled provided sufficient lifting power is available. After ascertaining that all control cables, chains, or rods are free, and in a fit condition to connect up, the planes should be hoisted into position and the spar attachments made to the upper and lower centre section. As soon as the plane spar attachments are made, the bracing wires for the inner bay should be connected up, starting with the inner anti-lift wires running from the upper centre section to the bottom of the inner pair of interplane struts. The same action should be taken on the other side of the aircraft to complete the assembly of the main planes.

268. The second method, generally adopted for small aeroplanes with a single set of struts and also for the larger multi-bay aeroplanes, is to erect each main plane separately. The order in which the planes should be fitted is usually determined for each type of aeroplane, and is generally given in the handbook. If the bottom plane is attached first, the bottom main plane spar attachments are fitted to their companion fittings on the fuselage or on the bottom centre

section stub plane, the outer end of the plane being meanwhile supported on a trestle at approximately the correct dihedral and incidence. The inner anti-lift wires should be attached as soon as possible.

269. The top main plane is then laid flat on a special felt-lined cradle and slung clear of the ground, and the interplane struts attached to the fittings provided on the underside. The next operation is to sling the plane into its correct position and to join the spars of the top main plane to the spars of the top centre section. A suitable form of lifting gear or crane should be provided for each type of aircraft, but if this is not available, temporary gear must be devised. Unless special sanction has been obtained, the roof of the shed or hangar should never be used. The interplane struts should next be fitted to the bottom plane, taking care that each strut mates correctly with its fitting as the plane is lowered. The bracing wires are then attached, and tightened sufficiently to make the structure reasonably rigid. The planes on the other side should be erected in a similar manner. When the main planes have been assembled, the transverse and longitudinal levelling of the fuselage should again be checked, and any necessary adjustments made. The centre section must be absolutely correct in rigging before any attempt is made to true up the main planes.

270. The engine may be fitted at any time during, or after the assembly of an airframe, but before doing so care should be taken to tie down the tail end of the fuselage to heavy weights resting on the ground, or to an eye-bolt or ring securely fixed in the floor, as otherwise the fuselage may tend to fall over on its nose. The tying down of the tail end is a wise precaution whether the engine is fitted or not. Care should be taken to see that the tying down does not put any strain on the fuselage. The rope should not be tighter than is necessary to take up the slack.

271. The attachment of the ailerons to the planes is usually undertaken before the planes are erected. During this process, some means must be taken to prevent damage due to the free movement of the ailerons, and a device such as that shown in fig. 106, and described in para. 466, should be used.

Truing up main planes.

272. The rigging notes for the particular type of aircraft being trued up will state the exact dihedral angle, and also the angular incidence of the planes and whether there is any "wash in" or "wash out." A typical rigging diagram is shown in fig. 77. In nearly all cases, specially prepared boards are provided to enable a rapid and accurate check to be made

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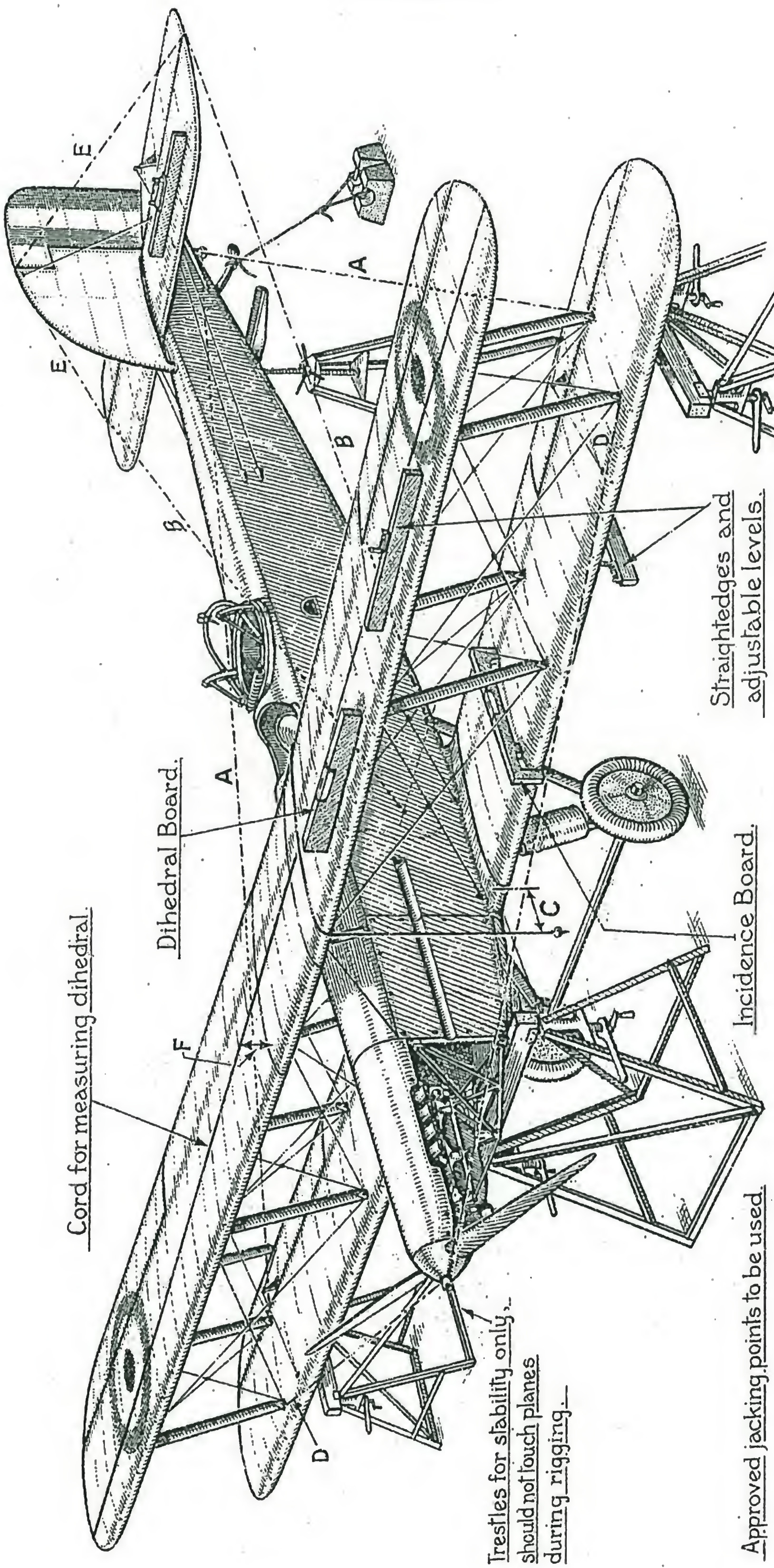

FIG. 79. TRUING UP A COMPLETE TRACTOR BIPLANE.

of the incidence and dihedral angles. Where these are not provided, the incidence and dihedral of a plane should be ascertained by using a straightedge and a clinometer. In those cases where dihedral is present as well as "wash in" or "wash out," the dihedral angle must be taken as that represented by the front spar.

273. In some types of aircraft, struts are employed instead of the interplane cross bracing wires, and in these instances little or no adjustment can be made unless the struts are made adjustable for length, which is not often the case. Normally, the dihedral of the lower main planes is fixed by the adjustment of the front landing wires, and is checked by means of the special dihedral board placed approximately over the front spar positions, as shown in fig. 79, or by using a straightedge and clinometer placed in a similar position. The dihedral angle may also be checked by using a cord stretched tightly over the tips of the top main planes and measuring the vertical height (F, fig. 79) from the cord to the plane and proceeding as given in para. 319. The stagger is adjusted by the cross bracing between the front and rear interplane struts, and is checked by measuring horizontally the fore-and-aft distance between a plumbline dropped from the leading edge of the upper main plane to the leading edge of the lower main plane. When an aircraft has a different degree of dihedral on the upper and lower planes, the stagger will not be constant throughout the span, because a plane which possesses a dihedral angle pivots about a line inclined to the horizontal at an angle which is governed by the angle of incidence. Thus an increasing set-back is given to the plane as it moves from a position of no dihedral to a limiting position of 90° dihedral angle, the circle described by the tip to the leading edge not being in a vertical plane. The set-back is rarely of any great magnitude and is only found when upper and lower planes have different dihedral angles. As an example, if a 5° dihedral angle is given to the planes of a biplane which are twenty feet from root to tip and have 5° angles of incidence, the wing tip of the lower planes would be set-back about 1·8 in. behind a plumb line dropped from a corresponding point on the upper plane.

274. The incidence of the main planes, as defined in para. 19, is adjusted mainly by means of the rear landing wires, but the incidence bracing between the front and rear pairs of interplane struts must be adjusted at the same time as the landing and flying wires. The incidence is checked by means of a clinometer resting on a straightedge which is pressed against the lower surface of the plane along one of the ribs, or by means of the special incidence boards which are prepared for the purpose, as shown in fig. 79. The usual procedure with

many of the smaller types of aeroplanes is to get the dihedral right first and, provided that the centre section has been properly rigged, the incidence and stagger should then be correct, or require but little adjustment. The correct rigging of a large aeroplane is often only achieved after repeated adjustments and continual checking. If the appropriate instruments are not available, it is possible to check the incidence and dihedral angles by using a straightedge and spirit level. With the aircraft in rigging position, the straightedge is suitably disposed beneath the plane (on trestles or by clamping to struts) and levelled with the spirit level. The angle is then ascertained by measurement as indicated in para. 322.

275. Before leaving the wings, they can be finally checked to see that they are symmetrical with the fuselage by measuring the distance on each side from some convenient pair of fixed points near the tips of the planes to a fixed point on the centre line of the fuselage near the tail skid, and also that the incidence, dihedral and stagger on each side of the aircraft are equal and correct. It is probably best to check symmetrical erection of the main planes by measuring from the top and bottom of the rear outer strut fittings to the stern post, and also from the centre of airscrew shaft to the outer front strut fittings, as shown at A and D, fig. 79.

276. There is a tendency towards the restriction of the use of the datum line to the truing up of the fuselage only, and to the referring of the angles of incidence of the tail plane to the incidence of one of the main planes. In this case the incidence of the lower plane centre section should generally be taken as the key to which the other angles, including the angle of the tail plane and that of the remaining main planes, would be referred, but the rigging diagram or the handbook will give all the information required in this respect.

Truing up tail unit.

277. Normally, the stern post (sometimes called the fin post) is vertical. The longitudinal centre line of the fin generally coincides with the centre line of the fuselage, whilst the tail plane is laterally horizontal and also symmetrical about the centre line of the fuselage. If the tail plane spars are not tapered, this component is very easily checked transversely with a straightedge and spirit level. If the spars are tapered, it is necessary to know the height of the packing blocks which must be inserted between the straightedge and the tail plane tip, and the position of these blocks, before the straightedge and spirit level can be used. It would be advisable to make up a tapered board for use with the spirit level if tail

planes of this type have to be checked frequently. If packing blocks are to be made up, it is always possible to obtain the correct height by trial and error.

278. The tail plane must be symmetrical on either side of the fuselage, and this may be checked by taking measurements on each side from the tips of the tail plane spars to some convenient pair of fixed points on the fuselage or lower centre section, as, for instance, the rear undercarriage strut attachments, or the rear spar attachments of the lower main planes. If the measurements taken are equal and the tail plane spar is in one straight line, this spar will be at right angles to the centre line of the fuselage.

279. The method of measuring tail plane incidence is indicated in fig. 80. The height of the packing blocks may be given to the rigger, or it may be necessary to make these up by the process of trial and error, the relative heights being correct when the distances marked A are equal at front and

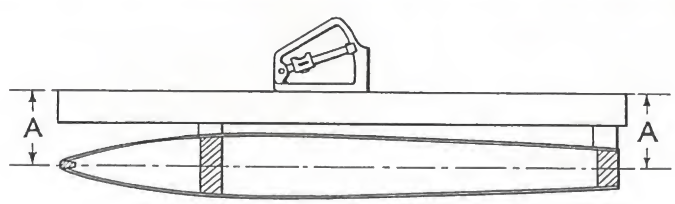

FIG. 80.—Measuring tail plane incidence.

rear. If the tail plane incidence has to be measured often, it would be advisable to make up an incidence board on the lines of the incidence boards for the main planes. Before proceeding to measure the incidence of the tail plane, care must be taken to place the tail adjusting gear in the normal position, as indicated in the rigging instructions.

280. Occasionally, for single-engined aeroplanes, the designer will have made the fin offset from the centre line of the fuselage in order to counteract the rotary effect of the airscrew slipstream. When this is done, the rigging instructions will generally specify the amount of offset, usually the distance in inches, between the longitudinal centre line of the fuselage and the centre line of the leading edge of the fin.

Locking bracing wires.

281. All bracing wires must be definitely locked, the usual method of doing this being by means of locknuts made of cast iron or brass. The nuts are composed of this material so that, if too great a pressure is used the nuts will split or the threads strip before the bracing wire is over-stressed at this

point. In addition to the locking of the wires they must be prevented from vibrating excessively, as otherwise wires which cross one another, and are in contact or are in close proximity, will suffer considerable damage. Also, from the wireless reception point of view, intermittent contact must be avoided. (This point is mentioned later in connection with bonding and screening). The usual method for internal wiring is to use a flat disc of red fibre, attached by soft iron wire or cord, between bracing wires where they cross, as shown at A and B, fig. 83. A grooved disc is also used as shown at C. Where duplicate wires are used externally, "acorns" are generally employed as shown at E, but sometimes the front and rear lift and anti-lift wires are connected as shown at D. Where the effects of vibration are very severe, twin bracing wires are attached to one another about midway between the intersection of the wires and the fork ends, by a fitting of the type shown at F.

282. It must never be immediately assumed that because a wire is observed to be slack, this particular wire requires tightening up. Investigations must be made before tightening up a slack wire to ensure that the slackness is not due to over-tightness of another wire, or to damage which has escaped observation.

Flying controls.

283. The flying control system of modern small aeroplanes is usually very simple, and an example of a common arrangement is given in figs. 81 and 82. In the larger aeroplanes the

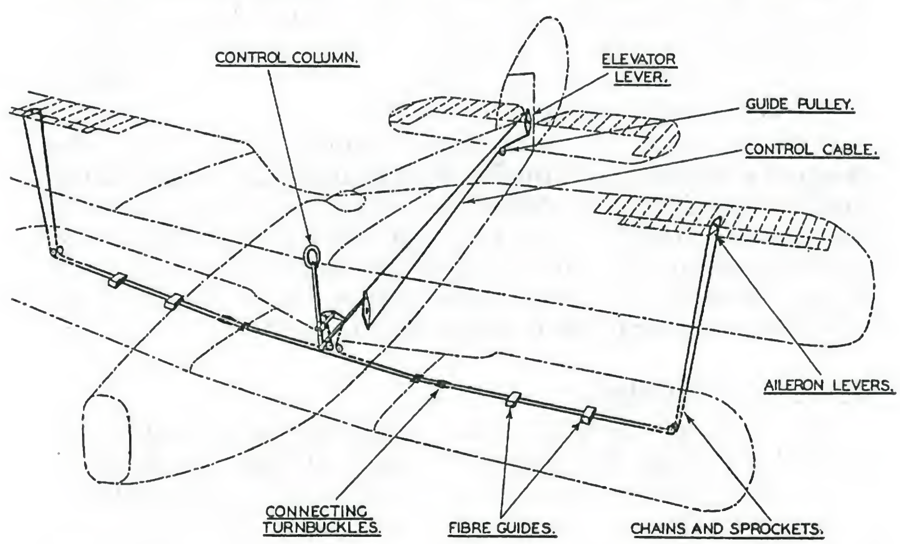

FIG. 81.—Control system—aileron and elevator.

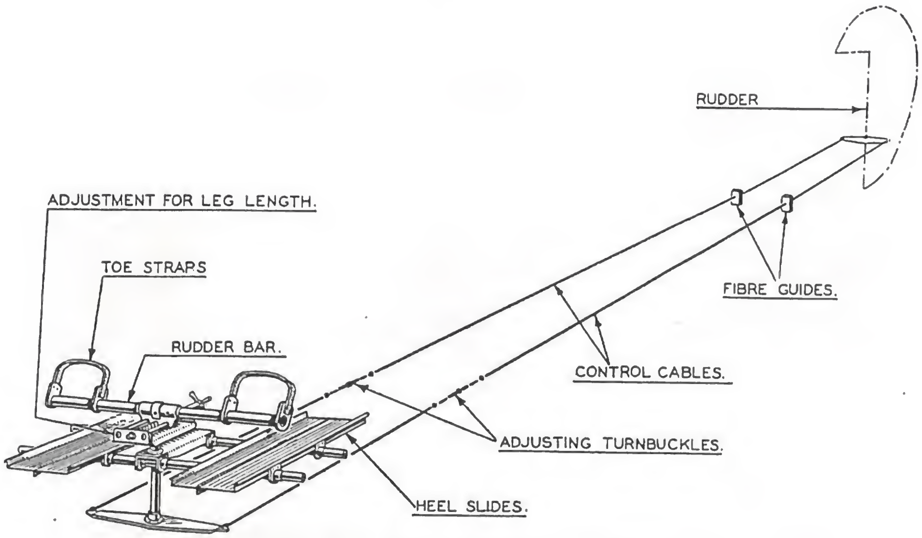

FIG. 82.—Control system—rudder.

control system is of necessity rather more complex, but the principle is the same as that illustrated. Before assembling the supporting and control surfaces, care should be taken to see that all control cables, chains, rods and levers are in a fit condition to connect up.

After assembling the aerofoils and coupling up the controls, adjustments should be made so that the cables and other parts are fairly taut, but work without undue stiffness, and that all control surfaces when in their neutral position are symmetrical about the centre line of the aeroplane. The control column is not always vertical when the elevators are in line with the tail plane, but is not infrequently inclined forward when in the neutral position. The rigger will always have specific instructions on these points. After connecting up the controls, the rigger should sit in the pilot's seat and operate all the controls one at a time, to see that the full range of movement is obtained, that the controls are not stiff in action and that the control surfaces move in the right direction following a corresponding movement of the rudder bar or control column. It is vitally important to check that a forward movement of the control column drops the elevators, that a movement to the right drops the left or port aileron and raises the right or starboard, and that a movement to the left reverses this motion.

Ailerons, setting of.

284. In order to allow for the stretch of the cables when under load, ailerons are sometimes given an initial droop, that is, the trailing edge of the aileron is set a little lower

than the corresponding trailing edge of the plane. The amount of setting generally varies between $\frac{1}{2}$ in. and $1\frac{1}{2}$ in. measured at the trailing edge.

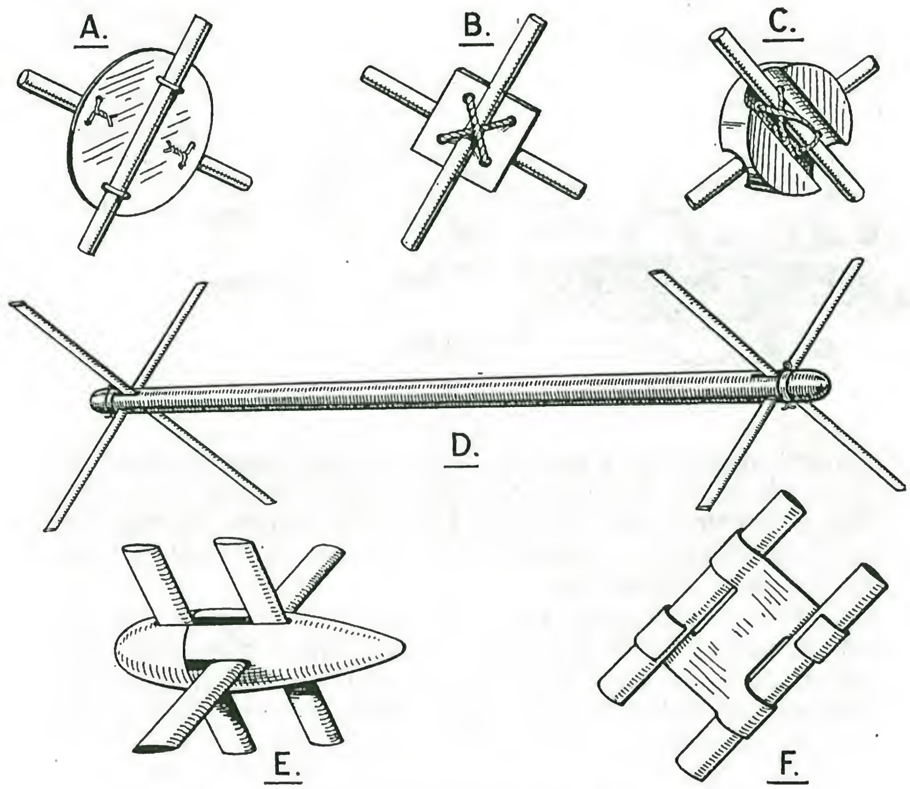

FIG. 83.—Vibration preventers on bracing wires.

Run of cables.

285. In the system illustrated in figs. 81 and 82 cables are used throughout, except at those points where the cables are deflected greatly out of their normal run. In positions such as these, chains and sprockets are adopted to obviate the rapid wear of cables, which is inevitable if plain standard pulleys are used. Where the wire is only slightly deflected (less than 5°), fibre fairleads are usually employed, generally split to facilitate the renewal of cables. In those instances where the cable is deflected more than 5°, it is normal practice to introduce a pulley and so obviate any unnecessary friction. Although the instances are getting rarer, there are still many aeroplanes in which plain control cables are used throughout the complete system. In many cases on these aircraft, comparatively small pulleys are used and there is often a deflection of the cable from its normal run of about 90°. In these cases,

the examination and renewal of the cables is an important item in the maintenance programme. The cable used is always extra flexible steel to B.E.S.A. Specification W.2, and it is specially manufactured and tested for this particular work, but in spite of this, it is not possible to make a cable which will last indefinitely if, in its working position, it is bent round a comparatively small diameter pulley.

286. For service aircraft it is usual to duplicate all control cables running to the rudder, and to the elevator also if they are interconnected in accordance with the general requirement. This duplication is a safeguard against loss of control should one of the cables become shot away or broken.

Control rods.

287. In many aeroplanes, especially of the larger types, single push-and-pull rods are used for the controls instead of flexible cables, as it is found that this form of actuating gear requires considerably less attention and fewer renewals. In this type of control mechanism the rods are usually composed of small diameter tubing, with suitable end fittings, connected to bell-crank or other forms of lever. When possible, the rods are supported at intervals throughout their length by small pulleys or similar devices, and are usually adjustable for length.

Adjustment of elevators.

288. In all the tail plane incidence control systems commonly in use, actuation of the incidence gear will to some extent affect the elevators in all positions except the normal flight setting. This makes it essential for the rigger to adjust the elevator controls only when the tail plane incidence is at the normal. The mid-position is always taken as the normal unless otherwise stated. The elevator control should be tested to see that it works smoothly at all positions of the tail plane incidence gear.

Variable camber gear.

289. For the purpose of giving a wider speed range to an aeroplane, the designer sometimes provides additional flaps which are hinged to the rear spars and situated usually inboard of the ailerons. The pilot is given a separate control by means of which he may depress these flaps and so virtually alter the camber and incidence of the wings. In practice, the variable camber is normally used only when it is desired to land at as low a speed as possible. When this gear is fitted, any specific instructions required for adjustments are usually included in the rigging notes of the aeroplane.

Auto control slots.

290. Where automatic slots are fitted, these are usually built up with the wing and should need very little attention other than lubrication of the bearings. When for any reason it has been necessary to dismantle a slot, there should be no trouble with its functioning after reassembly, provided that the setting of the gap at the trailing edge of the slot is as stated for the type, or is arranged as it was before dismantling. Fig. 54 shows a typical arrangement of an automatic slot. In this case the links and other parts are made to a fixed length, which precludes any adjustments being made, and definitely fixes the gap. Where adjustment is provided, care should be taken to get the setting correct, as otherwise the slot will not open at the correct time. Automatic slots are inclined to open sooner than is required if the trailing edge gap is too small.

Rudder bias gear.

291. Some aeroplanes are fitted with an arrangement by which the rudder is given an initial setting to one side. This gear is usually operable from the pilot's seat. The object is to allow the pilot to set the rudder during a long straight flight for the purpose of counteracting uneven engine thrust or similar defects, thereby obviating the tiring effects of continual pressure on the rudder bar. It is only necessary to see that the bias gear operates correctly, and that no bias is applied during the time that the rudder control cables are being adjusted.

Auilixary rudder control.

292. An auxiliary rudder control is usually only fitted to those aeroplanes provided with a bomber's slot in the bottom of the fuselage. The auxiliary control is usually coupled up to the rudder bar or to the rudder control cables, and needs little attention other than to see that it functions correctly and in no way impedes the action of the rudder bar.

Servo rudder.

293. A servo rudder is an auxiliary control surface, operable by the pilot, which actuates the main rudder, thereby making the aeroplane less tiring to fly. A servo rudder usually takes the form of either a narrow flap along the trailing edge of the main rudder, or a small, square auxiliary surface, placed 2 or 3 ft. behind the main rudder and attached thereto by outriggers. The control is usually very effective, and therefore in order to provide the pilot with some resistance

when operating the rudder bar, it is common practice to give the servo rudder some form of spring loading. Another device connected with servo rudders is called " follow up," and consists of the provision of some mechanical arrangement whereby the main rudder comes into direct operation by the rudder bar after the servo has been moved over to the full extent allowed by the stops.

294. The adjustment and lining up of a servo rudder is quite simple, as it is only necessary to see that the servo rudder and the main rudder are in line with one another and also in line with the plan centre line of the aeroplane when the rudder bar is transversely square with the fuselage.

Lubrication of controls.

295. One of the chief difficulties in the maintenance of control systems is the adequate lubrication of the bearings in the planes. Not only is the lubrication of these parts difficult, but even when lubricated care must be taken that the lubricant does not solidify or freeze during the extreme cold encountered at high altitudes and lock the controls, or make them exceedingly difficult to operate.

296. It is usual to employ anti-freezing oil, Stores Reference 34/43 and 46, and grease in any form should be avoided for the bearings of flying controls. (*See* Air Ministry Technical Order 143 of 1930). This means that parts which would normally be packed with grease and left an indefinite period will need attention a little more frequently when oiled with anti-freezing oil. Fibre fairleads should not be lubricated. Protection against corrosion will be dealt with in detail later, but cables or wires must not be covered over with paint or any substance which prevents immediate inspection of the part.

Examination of controls.

297. All well-designed control systems provide ample opportunities for examination of all the joints, connections and bearings, usually by means of tear-off patches or small sliding light alloy doors in the planes, and easily detachable fairings on the fuselage. The types of tear-off patches used are shown in fig. 105. Adequate arrangements are generally made for renewal of cables, and where the cables are long, such as in the interior of some of the larger planes, it is not unusual for the cables to be built up in sections, so that if only a small portion is defective the whole length need not be replaced. Where no definite arrangements are made for the renewal of cables in planes, a new cable can generally be introduced in the manner described in para. 459.

298. The control mechanism should be frequently inspected for corrosion, wear, frayed cables and incipient fractures or cracks, and also to see that all the locking devices, such as split pins, are in position and are secure. Where turnbuckles are used these must be securely locked with soft iron wire as shown in fig. 73.

Inspection.

299. The necessity for accurate, intelligent and systematic inspection of aeroplanes cannot be too greatly emphasised. It is of vital importance that all aeroplanes in service should be very thoroughly examined and that these examinations should be made in accordance with a set routine. The routine is usually detailed in the maintenance schedules for the type (*see* Air Ministry Weekly Order 25 of 1929), and the schedule, including any amendments made, should be strictly adhered to.

300. If an aeroplane has been subjected to a heavy landing or to any treatment which may adversely affect the structure, all the parts affected, or likely to be affected, should be examined in minute detail, in order to ascertain the exact extent of the damage.

301. After re-assembly, necessitated by repairs, the aeroplane should be completely inspected before it is passed as fit for flying. The inspection should be made methodically and in accordance with a system. The system usually adopted is to divide the aeroplane into a number of logical and convenient groups, and deal with each group in a definite order. The grouping normally employed is :—undercarriage, fuselage, tail unit, cockpits, mainplanes, airscrew and general. During the inspection of each group the inspector should, as far as the group lends itself to such procedure, always go round it in an anti-clockwise direction, examining each individual part in detail as it is encountered.

302. Every airframe has a log book which accompanies it throughout its service life. In the log book are recorded all matters bearing upon the life or serviceability of the airframe. In addition to the log books, there are Weekly Aircraft Maintenance Forms in which are recorded all matters dealing with the routine inspection and maintenance of the aeroplane.

Rigging defects and remedies.

303. The following list of faults, with their possible causes and remedies, is given only as a guide to the rigger when ascertaining the reason for a defect which has been reported after flight. In all cases the rigging notes and instructions

for the particular aeroplanes, contained in the handbook or elsewhere, should be rigidly adhered to.

Symptoms.—Tendency to yaw, i.e., does not fly straight.

Cause.—Resistance not the same on both sides ; may be caused by one of the following :—

(*a*) Fin not in alignment, giving the effect of slight rudder.

(*b*) Fuselage not in correct alignment, giving an effect as in (*a*).

(*c*) Resistance greater on one side than the other, due to such causes as wires or struts not being in true line of flight, distorted surface, bombs, generators, etc.

(*d*) Elevators not in alignment with tail plane on one side, giving slight torsional effects and greater resistance on one side.

Symptoms.—Tendency to roll, i.e., inclined to fly one wing down.

Cause.—Lift greater on one side than the other, which may be caused by one of the following :—

(*e*) Incidence of the main planes greater on one side than the other.

(*f*) Ailerons out of alignment with control column central.

(*g*) Dihedral greater on one side than the other.

(*h*) Surfaces distorted, giving greater or less lift on one side.

(*i*) Unequal distribution of the load due to wing tanks, bombs, etc., giving, in effect, unequal wing loading.

Symptoms.—Nose or tail heavy.

Cause.—(*j*) Stagger incorrect.

(*k*) Incidence of tail plane incorrect.

(*l*) Incidence of main planes the same on both sides, but incorrect.

(*m*) Loading incorrect. (This should never occur, as the correct loadings between the limits of the C.G. position are always given).

304. In addition to the above, it is possible for certain rigging defects, such as the incidence of the main planes or tail plane not being the same on both sides, to give a slight tendency to yaw during flight as a secondary effect (as at (*c*)), the primary having been corrected by the pilot.

305. It should be noted that there will probably be a tendency to yaw with the engine off, due to the offset fin or " wash-in " of the planes. This must not be confused with the tendency to yaw in steady level flight.

Rigging allowances.

306. Rigging notes and instructions generally give the angles and dimensions in exact figures, but in practice it is seldom possible to work to the exact dimensions given. A tolerance is therefore permissible on all dimensions.

307. The allowances to be made vary with different aircraft, obviously depending mainly on the type and size of the aeroplane and the magnitude of the dimension. Table V may be taken as a guide as to what limits may reasonably be allowed, under good conditions, for a small high-performance tractor biplane of the Siskin or Bulldog type. *It must be distinctly understood that the tolerances on a larger aeroplane or on an equal-sized aeroplane of a different type* (*Avro* 504.*K. or Moth, for example*) *may be very different. The utmost care must be taken to avoid damage to the structure owing to an attempt to work to too strict a tolerance ; on the other hand, no effort should be spared to obtain the closest approximation to the rigging dimensions that the normal adjustments will allow.*

TABLE V.

(NOTE.—This table must be used strictly in the light of para. 307.

Checks.	Limit.	Remarks.
Top centre section for being central.	± 1/16 in. ..	" A " and " B," fig. 78.
Top centre section for incidence	± 10 mins. ..	See fig. 4.
Main planes, dihedral ..	± 15 mins. ..	See fig. 4.
Main planes, incidence ..	± 15 mins. ..	See fig. 4.
Main planes, stagger	± $\frac{1}{8}$ in.	" C," fig. 79.
Main planes, gap variation throughout span.	± 1/16 in. (1/32 in. in 3 ft.).	
Symmetrical rigging, rear diagonals.	± $\frac{3}{4}$ in.	" A," fig. 79.
Symmetrical rigging, front diagonals.	± $\frac{1}{2}$ in.	" D," fig. 79.
Tail plane alignment, lateral	± $\frac{1}{4}$ in.	" B," fig. 79.
Undercarriage alignment, lateral.	± $\frac{1}{4}$ in.	" A," fig. 76.
Undercarriage alignment, longitudinal.	± $\frac{1}{4}$ in. ..	" C," fig. 84.
Rudder post alignment, vertical	± $\frac{1}{8}$ in.	" E," fig. 79.

CHAPTER X.

TRUING UP ON BOARD SHIP.

308. On board ship where a level and steady platform is not available, or the aeroplane cannot be held dead still, the normal operations for rigging cannot be used. In these circumstances special methods must be adopted. Unless the aeroplane has been damaged or dismantled for any purpose, it is not likely that many rigging adjustments will be required for modern all-metal aeroplanes under normal service conditions.

309. The usual method of checking the rigging of an aircraft on board ship is to check the length of wires and other parts against a list of dimensions previously obtained. This will necessitate a record being made on shore of all the important dimensions when the aeroplane is correctly rigged. The dimensions recorded will be mainly connected with the length of wires between pin centres, or preferably the diagonal distances of the bracing between definite marks on the fittings. The dimensions recorded should be as accurate as possible, say to the nearest $\frac{1}{16}$ in., as otherwise it will be impossible, at times, to determine the smaller variations in lengths. It will be difficult to measure to as fine a degree as this for some parts, therefore it may be advisable to inset in the fabric, or attach to struts, small light alloy plates or clips which have been marked with a centre punch. On occasion, such as when a new plane has been fitted, it will not be possible by the above method to get the aircraft correctly rigged at the first attempt, and it may be necessary to give the new wing a little "wash in" or "wash out" in order to rectify the flying defect reported.

310. Where the method of checking by measurement is not applicable, the following methods can be used:—

Ship plane fuselage.

311. Similar methods of truing up the side frames of a stripped fuselage can be used on board ship as are used on shore. These methods are described in para. 217 (i) to (v) and illustrated in fig. 72, and consist of stretching cords (or preferably lengths of No. 18 white thread) along each side of the fuselage at datum line height, just clear of the side members. The threads or cords are tied to horizontally disposed straightedges, which project from either side of the fuselage, attached to the front and rear struts. A carpenter's square is then used, to ascertain if the top longerons are the correct distance from the threads, as given in the rigging notes. The transverse panels are then roughly trued up by measuring the diagonals at each vertical strut. As plumb lines cannot be used, the top and bottom frames of the fuselage

are trued up in a similar manner to the side frames, that is by means of threads or cords above and below the fuselage, stretched between vertically disposed straightedges or laths clamped to the centre of the front and rear cross struts as shown at A, fig. 84. The side lines should be maintained in position during this operation, as the truth of the side frames will probably be disturbed by the adjustments made to the top and bottom frames. The top and bottom lines must be so disposed that, as ascertained by using a carpenter's square, they are at 90° to the centre marks made on the front and rear cross struts. Adjustments are then made until the top and bottom longerons are equidistant from the threads on either side, or the centre marks made on all the cross struts are in line with the threads.

312. In those cases where it is merely required to check the truth of the fuselage of a completed airframe, the procedure will be similar to that already described for landplanes in para. 213 with the exception that, of course, spirit levels cannot be used. Two straightedges are used, laid across the longerons, one as far forward as possible and the other positioned at a number of different points, and the top edges are viewed from the front or rear to check for parallelism. Symmetrical rigging is checked as given in para. 275 and shown at A and D, fig. 79. During all checking operations it is essential that the bracing wires should be at the correct tension.

Ship plane undercarriage.

313. The truth in front view of an undercarriage can be ascertained by measuring from similar points on the axle extremities to similar points on fittings on the opposite side of the fuselage, or by measuring the diagonal distances in line with the cross bracing wires or cables as shown at B, fig. 84. This operation will probably involve detaching the

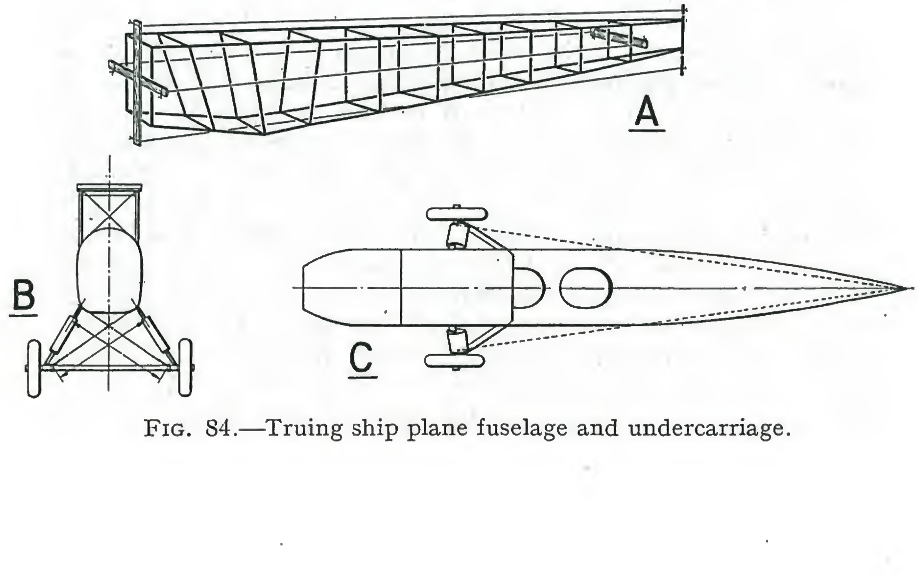

FIG. 84.—Truing ship plane fuselage and undercarriage.

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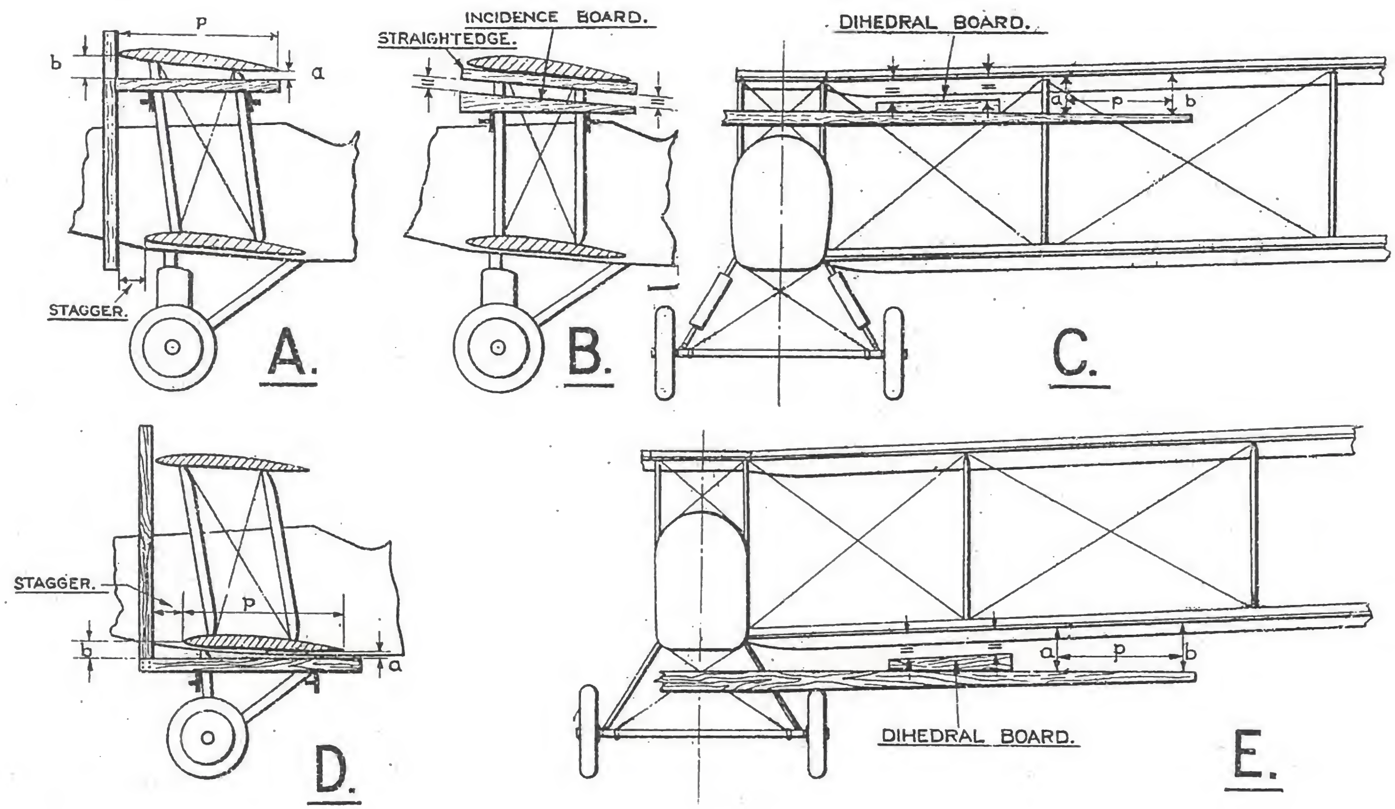

FIG. 85. TRUING SHIP PLANE MAIN PLANES.

P 3882.

undershield or bottom engine fairing. The correctness of the undercarriage in plan view can be checked by measuring from the same or similar points on either end of the axle to the sternpost, as shown at C, fig. 84. In both checks given above, the measurements on either side should be equal.

Ship-plane main planes.

314. An artificial marking-off platform should be built up from some datum line, e.g., the top of the fuselage rails, the top or bottom of the main wing spar roots, or from the datum line as transferred from the levelling plates or pegs provided. In the latter case the fuselage must be checked for truth before the main planes are checked.

315. The skeleton platform may consist of two long straightedges of a length equal to about half the span of the aircraft, plus half the length of the landing chassis, the top edges of these platform straightedges being square and true, and the sides braced against warping. The platform straightedges are held by special clamps to the top longerons, the top centre section struts, or the bottom main wing root spars. When the straightedges are held to the bottom main wing roots, they are attached to the undercarriage struts or other suitable parts, as indicated at E, fig. 85. In this case, accurately made distance pieces are placed between the top edges of the platform straightedges and the extremities of the bottom centre section. The distance pieces should preferably be made of metal and so constructed that they register up against definite fixed points, such as the front and rear spars, or the spar end fittings, for which purpose it may be necessary to cut the fabric or detach fairings. When so attached, the top surfaces of the straightedges should be transversely and longitudinally true with the fuselage, and would represent two lines on a horizontal truing-up board.

316. In many instances it will be difficult to attach the platform straightedges to the undercarriage struts or the bottom longerons, and so work from the underside of the lower planes. In these circumstances it will be necessary to make arrangements to work from the underside of the upper planes as shown at C, fig. 85. It may be possible to use distance pieces in this position also, in which case the operation is similar to that just described, with the addition that the top centre section must first be checked for truth. Where distance pieces cannot be used, or where it is necessary to check the alignment of the platform straightedges, the procedure given below is recommended :—

(i) Check the front and rear diagonals of the top centre section struts.

(ii) Temporarily clamp the two platform straightedges in position on the top longerons or the top centre section struts, in as near the final position as possible.

(iii) Measure from similar points at the top of the front centre section struts to points marked on the front straightedge which are equidistant from the centre line of the fuselage, and also from the same points on the front straightedge to the extremities of the bottom centre section, and adjust this straightedge until the distances measured on either side are equal. The front straightedge should now be transversely true with the fuselage.

(iv) Strip the covering from the fuselage, and place a straightedge, long enough to cover two bays if possible, on the levelling plates or parallel with the scribed datum line and clamp in position.

(v) Place two straightedges or round bars through the fuselage, resting them on the longitudinal straightedge, and clamp to adjacent struts. Ensure parallelism and transverse truth by measuring the height of the straight edges from similar points on the longerons to each straightedge on either side, and sight from the rear to check. The transverse straightedges should be as far apart as possible.

(vi) Tie a length of cord or No. 18 white thread to the rear transverse straightedge, and bring the line over this straightedge and the one in front. The line is then taken to the front of the fuselage so as to touch the fuselage fairing at a distance a little beyond the leading edge of the lower centre section stub planes, and raised or lowered until it just touches both of the rear transverse straightedges. A mark is then made on the fuselage side at the same height as the cord. It is advisable to do this several times, and select a mean position midway between the marks so made. Then, placing the line on a level with the selected mark, make a series of dots on the fuselage fairing, at the height of the thread, for a length somewhat greater than the cord of the main planes, and scribe a pencil line through the dots. A similar line should be made on the other side of the fuselage. These pencil lines will then represent the datum line of the fuselage.

(vii) Measure the vertical height from the pencil lines to the upper surfaces of the platform straightedges and adjust the rear straightedge until it is at the same height from the pencil lines as the front straightedge. The top surfaces of the two straightedges should then be parallel when viewed from the front or rear.

(viii) Sight from the rear across the platform straightedges and the rear transverse straightedges to ensure parallelism.

317. In some cases, cords tied to the outer interplane struts could be used instead of the platform straightedges. The alignment of the cords, and the rigging of the aeroplane, should be checked by measurement, as described for the platform straightedges.

Dihedral.

318. The best method of checking dihedral, when using the platform straightedges, is to use a dihedral board tapered to the same angle as the dihedral angle, and measure vertically from each end of the top surfaces of the dihedral board to the underside of the planes, at about the spar positions, with the board resting on one of the platform straightedges as shown at C and E, fig. 85. The distances so measured should, of course, be equal.

319. If dihedral boards are not available, the dihedral angle can be measured by taking the distance between the spars and the two platform straightedges, as shown in fig. 85, at points " a " and " b " at a distance from one another " p," and subtracting " a " from " b." The dimension so found, in conjunction with the distance equivalent to " p," thus forms the perpendicular and the base lines of a right-angled triangle. The actual position and distance apart of the points taken does not matter greatly ; but the further apart they are the better. Having these two dimensions, and referring to fig. 107, the angle can be ascertained directly. The angle can be easily found otherwise by referring to trigonometrical tables, as the tangent of the angle being measured is equal to $\frac{b - a}{p}$; all distances to be in inches. Take, as an example, the measuring of the dihedral of a plane where the perpendicular distances are 7·3 in. and 4 in., measured on a base line of 5 ft. 3 in. or 63 in. Then $\frac{7\cdot3-4}{63} = \cdot0524$. By referring to trigonometrical tables, it is found that ·0524 is the tangent of 3°, which is the angle required.

320. The dihedral can also be checked by joining the tops of the wings by a thread held taut, measuring the distance between the thread and the top of the main plane spars, as indicated at F, fig. 79, and proceeding as given above.

Symmetrical rigging.

321. This can be checked as already described in para. 275, and as shown in fig. 79 for landplanes. The check is made by

measuring the distances from the sternpost to similar points on either side of the aeroplane at each lower and upper wing extremities, such as the rear interplane strut fittings.

Incidence.

322. An incidence board should be provided, tapered to the same angle as the angle of incidence of the main planes when the aircraft is in rigging position. When the incidence is measured from a line tangential to the underside of the plane, the incidence board and a straightedge are disposed as shown at B, fig. 85, and the vertical distances at about the leading and trailing edges are measured from the top of the incidence board to the underside of the straightedge. The incidence of the plane will be correct when these distances are equal. When the incidence is measured from the chord line taken through the centre of the leading and trailing edges, the incidence board is used alone and measurements are taken from the leading and trailing edges to the board. These distances also should be equal if the incidence is correct. Another method which can be adopted, should an incidence board not be available, is to place a straightedge across the platform straightedges at right angles to the spars, as indicated at A, fig. 85, and measure the vertical distances between the top surface of the straightedge and the chord line at the leading and trailing edges. The method employed to find the angle is then similar to that employed for dihedral.

Stagger.

323. A large 90° or T-square is necessary to measure the stagger. By putting the bottom edge of the square on top of the two platform straightedges and placing the inner vertical edge of the square against the leading edge of the top centre section, the stagger can be measured by ascertaining the horizontal distance between the nose of the lower plane and the inner vertical edge of the square, as indicated at A and D, fig. 85.

324. If the top and bottom planes are parallel, the stagger must be checked in at least two positions along each wing. If the top wing only possesses sweepback, then the stagger can be measured at the centre section only.

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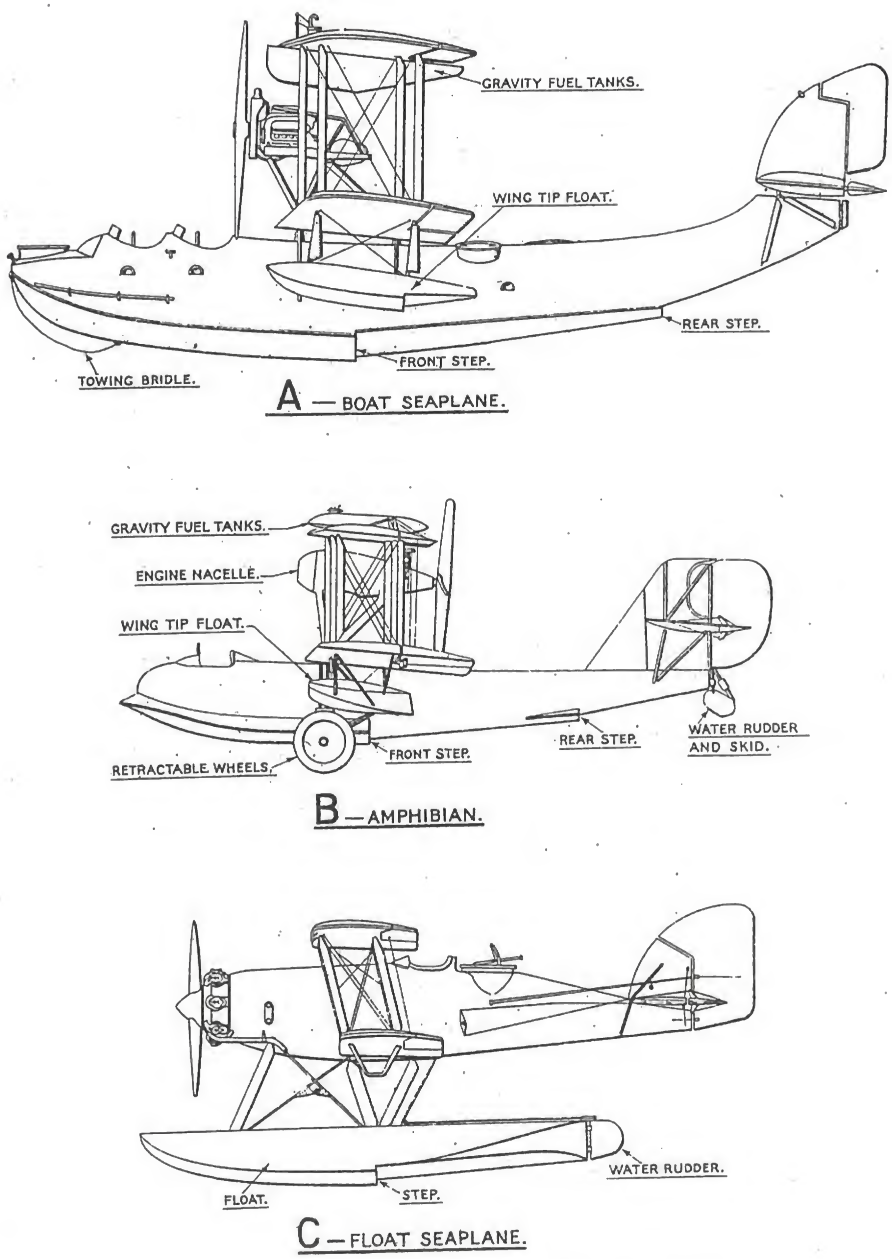

FIG. 86. BOAT AND FLOAT SEAPLANE AND AMPHIBIAN.

CHAPTER XI.

FLYING BOATS, FLOAT PLANES, AND SHIP-PLANES.

Flying boats.

325. Boat seaplanes are designed to take-off and alight on water, and have a central body or hull similar in many respects to that of a boat, in which the pilot and crew are accommodated. Wing-tip floats are usually necessary to ensure stability on the water, as indicated at A, fig. 86.

Float planes.

326. Float planes are also designed to take-off and alight on the water, but, except for the alighting gear, are similar to landplanes. The normal arrangement is to provide two floats, spaced well apart, which are fitted in place of the wheel undercarriage and tail skid used on landplanes as shown at C, fig. 86. In some cases alternative undercarriages are arranged, so that, at short notice, the aeroplane can be converted from a seaplane to a landplane or vice versa. Float-planes are sometimes designed with a central float and two wing-tip floats, but this is unusual.

Amphibians.

327. Amphibians, as the name implies, can be used on either land or water. These aircraft are usually seaplanes with some form of land-alighting gear attached. There are two usual forms, one of which is applicable to float seaplanes only, where the landing wheels are concealed in the floats in such a way that only the minimum amount of the tyres is exposed through the bottom of the floats, and the other type, shown at B, fig. 86, where the alighting wheels are arranged on some form of retractable undercarriage. The usual arrangement of undercarriage shock-absorbers and tail skids is normally provided. Amphibians are not a type of aircraft which, so far, have been very much used, as greater efficiency is obtained by those aircraft which are designed for use in the particular element in which they have to operate.

Seaplane flying structure.

328. Structurally, there is little or no difference between the flying structure of a boat or float seaplane and that of a landplane. The slight structural differences which do occur are mostly a consequence of the requirements peculiar to seaplanes, such as wing-tip floats, towing and mooring eyes and lifting tackle. The fitting of these parts and kindred devices usually entails the provision of additional strength in the members affected.

For seaplanes, greater precautions against corrosion are necessary, and for this reason, wherever possible, advantage is taken of the properties of stainless steel for the manufacture of fittings and important parts. All parts not of this material are usually well coated with an approved protective substance. This subject is dealt with at greater length in a later chapter.

Seaplane hulls and floats.

329. The design of all hulls and floats is very carefully considered to obtain " clean " lines, and in all cases water-tank tests are made (and in some cases wind-tunnel tests) in order to determine the best shape. In all cases hulls and floats are arranged with a large area of nearly flat surface on their underside, which is called the " planing bottom." This portion is set at the correct angle to the main body of the seaplane, so that, when propelled through the water at a sufficient speed, the reaction due to the incidence of the planing bottom raises the boat some way out of the water, thereby decreasing the area immersed, and consequently the resistance.

330. At one or more points along the length of the planing bottom there are steps, as shown at A and B, fig. 86, where the continuity of the bottom is broken, and that portion immediately aft of each step is arranged on a higher level. These steps are provided in order to eliminate as far as possible the longitudinal oscillations called " porpoising," by giving two or more points of support. The front step is usually disposed approximately under the centre of gravity of the aircraft. In front view it is usual to construct the planing bottom with a deep flared V-shape, which flattens out considerably towards the aft end. The object of this V-shape is to give, when landing, a more gradual impact with the water, and in conjunction with the flared bow provide a means of keeping down the bow wave by throwing the water outwards. In addition, the concave flared shape allows the plating to be in direct tension when under load, and thus prevents " panting" or partial buckling of the plates. The general shape is a compromise between the flat bottom which is the better for getting off and the sharp V which is the better for landing.

Wing-tip floats.

331. On account of the fact that the centre of gravity is considerably above the water line, some means of ensuring stability on the water must be incorporated for boat seaplanes or float seaplanes with a single central float. This is usually accomplished by means of wing-tip floats, but in some boat seaplane designs the same effect is obtained by providing short stub planes constructed as part of the hull, and placed low down on either side at approximately the water level. With

twin float seaplanes the floats are placed sufficiently far apart to give all the stability required.

Flotation bags.

332. When a ship-plane has no other form of flotation gear, it is usual to provide air bags to assist in keeping the aeroplane afloat should it inadvertently enter the water. The normal arrangement provides square-sided bags made of waterproofed fabric, which more or less completely fill each bay between the rear cockpit and the aft end of the fuselage.

Buoyancy factors.

333. Hulls and floats are always so made that their internal capacity provides greater buoyancy than is actually required to keep the aircraft afloat. The total volumetric contents of the hull is $4\frac{1}{2}$ to 5 times the volume of water displaced by the hull when the aircraft is fully loaded. This is termed the buoyancy factor. For floats the factor is usually 2; that is, 100 per cent. greater than the minimum required to keep the seaplane afloat. Wing-tip floats usually have a buoyancy factor of about 5 on the upsetting moment produced by the height of the centre of gravity above the water.

Water rudders.

334. Water rudders are sometimes provided for seaplanes, usually operated by the rudder bar and situated on float seaplanes at the aft end of the floats as indicated at C, fig. 86, in a similar position to that occupied by a normal ship's rudder. Water rudders are seldom used for boat seaplanes, mainly because all the control normally required is obtained from the engines, of which there are usually two or more. For single-engined boat seaplanes the water rudder, when not positioned at the aft end, sometimes takes the form of retractable fins, which in operation project from the sides of the hull.

Wooden hull construction.

335. Originally, the hulls and floats of all seaplanes were constructed of wood, and were in many cases built in a similar manner to the monocoque type of construction illustrated in fig. 42, the normal design having a circular or oval formation in cross section, with the addition of a planing bottom attached to the underside.

336. The main disadvantages of the wooden type of construction are that hulls and floats made of wood are heavier, leak to a much greater extent than a similar metal structure, the water absorption is relatively great (being about 300 lb. for a boat seaplane of about 12,000 lb. weight), and the repairs

and maintenance required are excessive, especially in tropical climates. Further, when a wooden hull or float is damaged, the effect is not local, as it is usually with metal hulls, but necessitates the opening up and renewal of comparatively large areas. Also, there is usually a certain amount of trouble with wooden hulls at the junction of the flexible planing bottom and the comparatively rigid body.

Metal hull construction.

337. The first metal hulls and floats were constructed of duralumin, and apart from corrosion were satisfactory. This material is still being used extensively, but gradual progress is being made towards utilising stainless steel, not only for hulls and floats, but for all purposes connected with seaplanes.

338. There are two normal methods of constructing metal hulls and floats. The main differences, other than the shape and the detail design of the parts, are that whereas some hulls are constructed in sections with bands or rings of sheet material which are joined end to end, as shown in fig. 87, others are made with strips or plates which are laid lengthwise on to a skeleton frame and connected edge to edge, as indicated in fig. 88. In both methods formers are used to give and retain the desired shape, but in the former method stiffening angles or channels are used between the formers to stabilise each ring, whilst in the latter method stringers are used which run the whole length of the hull and to which the longitudinal plates are riveted.

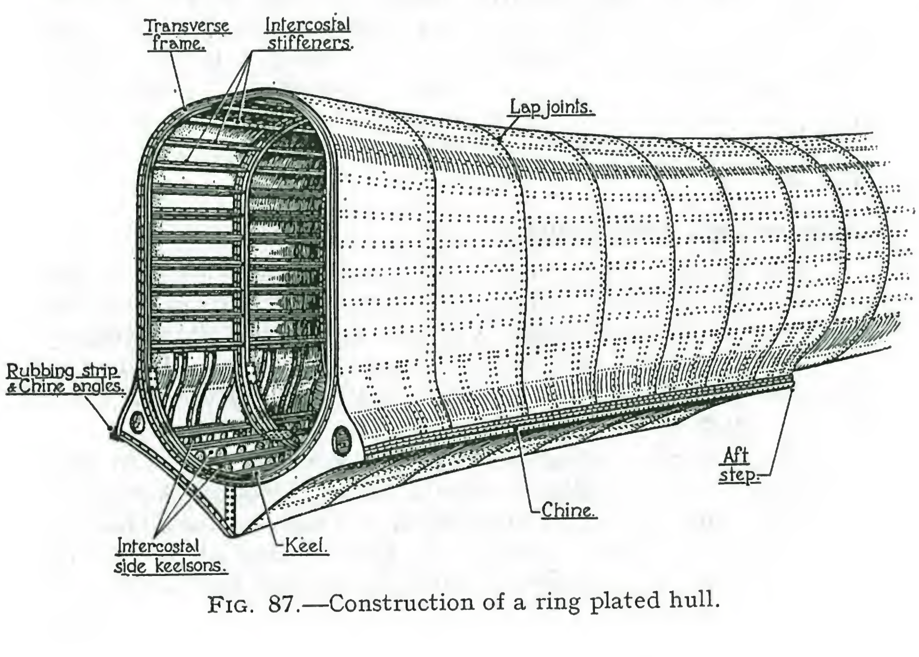

FIG. 87.—Construction of a ring plated hull.

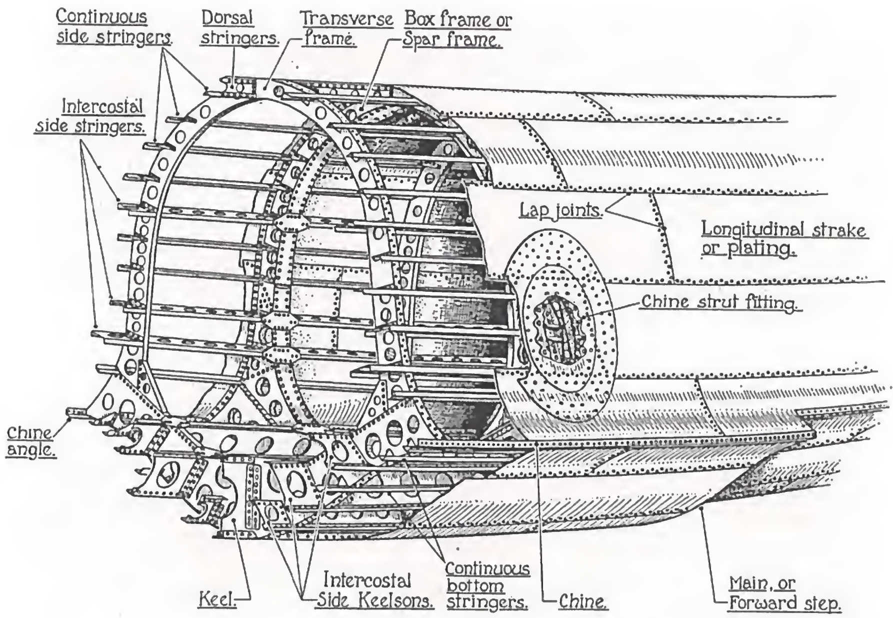

FIG. 88.—Construction of a longitudinally plated hull.

Rigging.

339. The rigging of flying boats and float planes is practically identical with the rigging of landplanes. A little difficulty may be encountered in placing a boat seaplane in rigging position, unless special equipment is available. The type of equipment necessary usually takes the form of a special type of adjustable trestle, such as is described in para. 353. This is placed under the lower planes at special jacking points, generally in the neighbourhood of strut fittings.

Launching and beaching gear.

340. It is necessary to provide special facilities for handling boat and float seaplanes on land, and for launching and getting them ashore. Seaplane stations are provided with a slipway, which varies in length and slope according to the local conditions, but is usually built at a slope of between 1 in 20 and 1 in 35. A wooden ridge usually runs down each side of the slipway projecting above the level of the top surface. In addition, where the tidal currents sweep strongly across the slipway, it is necessary to have side piers or gantrys from which assistance is rendered as required. At the head of each slipway there is usually a winch, electrically or motor operated, to assist in lowering and hauling in.

341. During these operations it is necessary to take special precautions against damage to the hulls and floats, and for this purpose some form of trolley is normally available. Boat seaplanes are generally provided with a large beach trolley or a special kind of detachable launching chassis of the type shown at A, fig. 89. A tail trolley is necessary, in addition, when the latter form of chassis is used. Float seaplanes are usually handled by means of a trolley of the type shown at B, fig. 89, or by some form of detachable wheels, which are attached to the floats.

SEAPLANE EQUIPMENT.

342. The equipment of boat and float seaplanes differs from landplanes only by the addition of several items. These items, most of which are described in the following paragraphs, are mainly associated with the handling of seaplanes at sea, and more generally apply to boat seaplanes, as in the first place there is the necessary accommodation available, and secondly, the additional weight involved is not of such vital importance.

Anchor.

343. Boat seaplanes are usually provided with some form of stowage space for a light anchor of between 30 and 80 lb. weight, and a considerable length of cable. The anchor, when carried, is intended for use in sheltered harbours and in good weather as, on account of its light weight, it is of little use in a stiff breeze or when a strong tide is running. Aircraft anchors are difficult to standardise on account of the variable conditions of usage ; the one shown at A, fig. 90, is the Felixstowe, Mk. 12A, and weighs 70 lb.

Drogue.

344. A drogue is a conical fabric tube, very much smaller at one end than the other, with a metal hoop at the larger end to keep the mouth open, as shown at B, fig. 90. A riding bridle, composed of three or four lines, is attached to the hoop, and is connected to the heaving line by a swivel and spring hook. The normal size of drogue is about 2 ft. 6 in. long by 2 ft. diameter at the large end and 6 in. diameter at the small end. A light tripping line is attached to the small end to facilitate hauling in. Drogues are used for checking the forward speed and drift of a seaplane, and assist generally in the manoeuvring.

Boat hook.

345. Boat hooks designed for use on seaplanes do not usually take the simple form of the hook generally used, but

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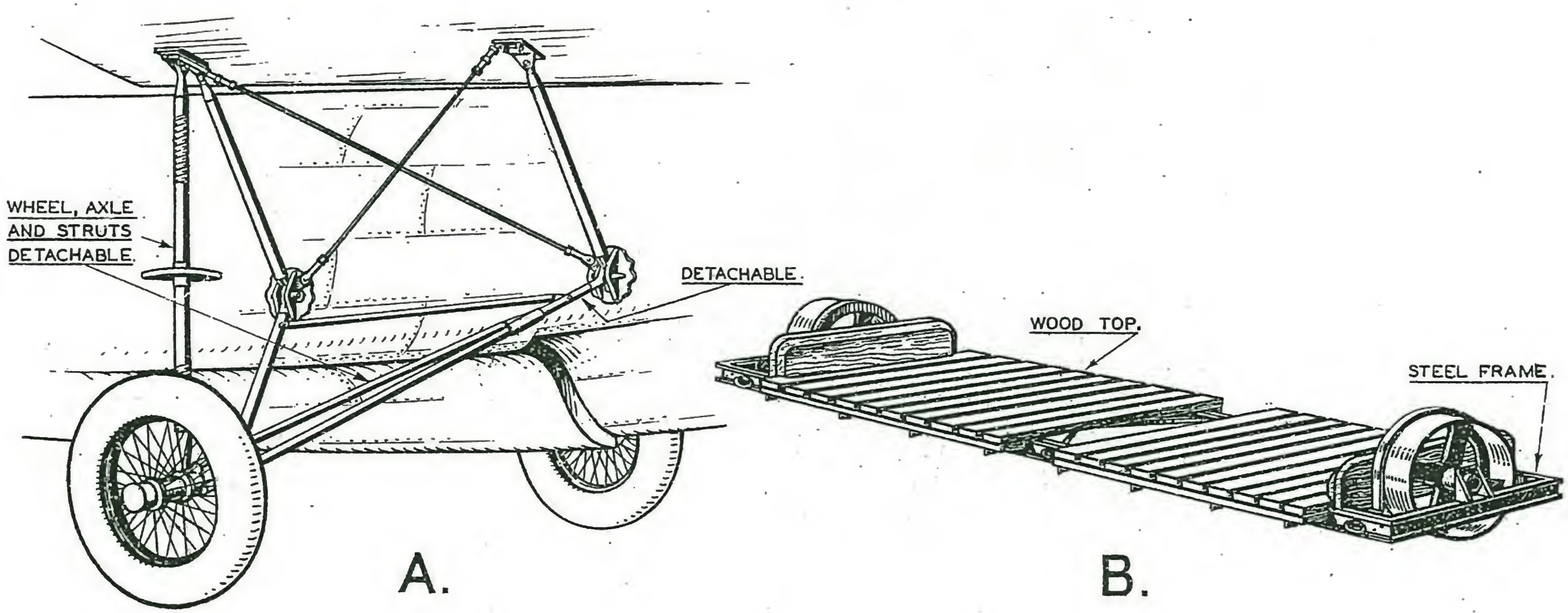

FIG. 89. LAUNCHING CHASSIS AND BEACHING TROLLEY.

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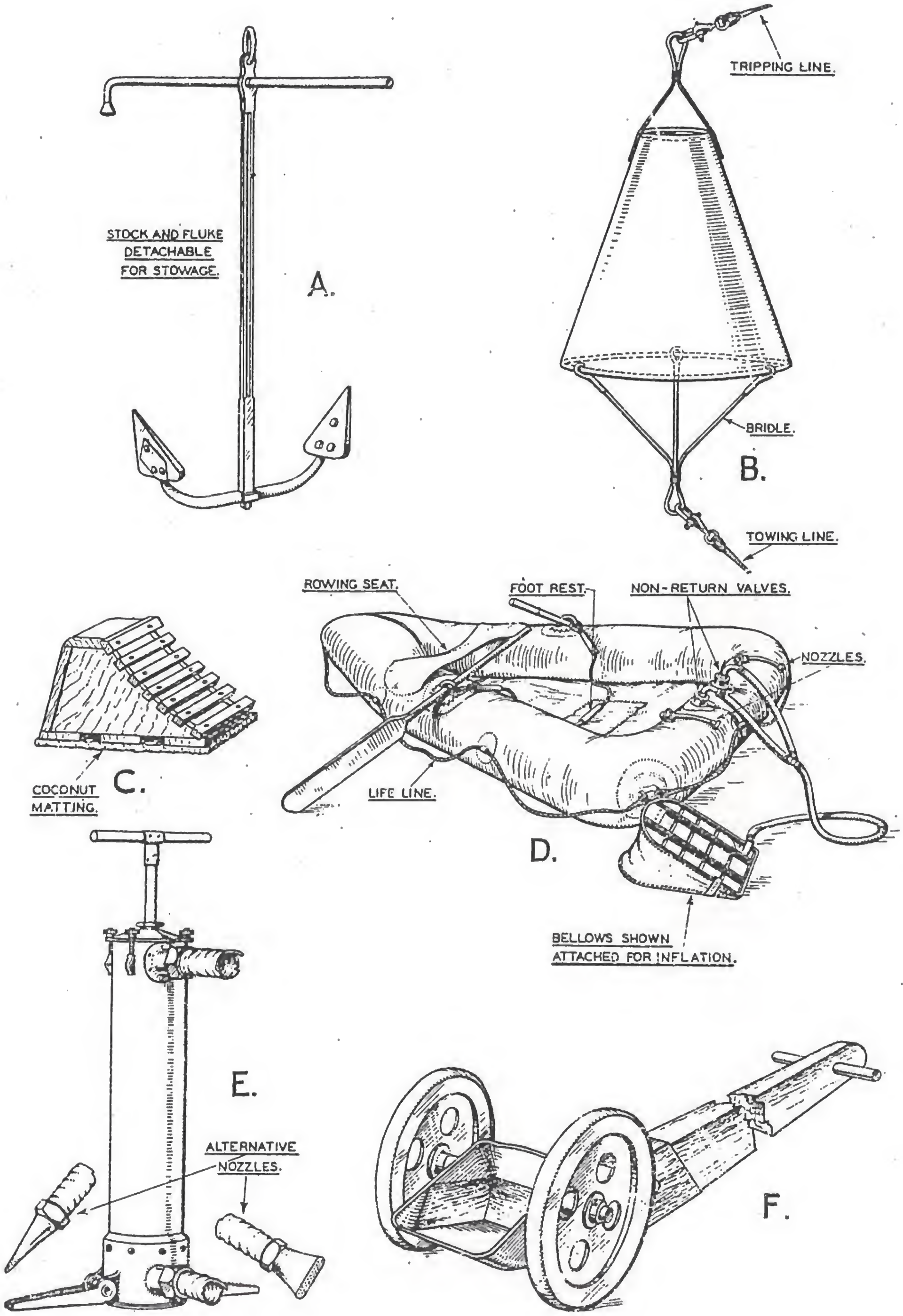

FIG. 90. MISCELLANEOUS SEAPLANE EQUIPMENT.

P.3882.

are a special type, embodying some form of spring hook device which enables the aircraft to be quickly and easily moored up to a buoy.

Dinghy.

346. A boat seaplane usually carries a collapsible pneumatic dinghy, such as that shown at D, fig. 90, which is stowed in a cylindrical bag 15 in. diameter, 2 ft. 6 in. long. The triangular shape chosen has been found to possess many advantages and is very satisfactory in service. A pair of oars, a pair of bellows, and a repair outfit also normally accompany the dinghy.

Bilge pump.

347. Some form of bilge pump is essential for all seaplanes. The types in use may vary considerably on account of the trouble which has been encountered in devising a pump which is capable of doing the work required, but which at the same time is not too heavy to be carried in the air. The pump shown at E, fig. 90, is the hand type which is normally used. This pump is capable of delivering up to 500 gallons an hour and has a flexible hose connection, with two shapes of nozzle for insertion into the various hull compartments, through suitable apertures formed in the floor. In addition to the hand bilge pumps, a power-driven type is being developed for use on the larger aircraft.

Chocks, aeroplane wheel (aircraft carrier).

348. The ordinary type of wooden chock is not used on board ship. A special form is employed, shown at C, fig. 90. which has cocoanut matting attached to the underside to prevent slipping on the metal decks.

Mooring and towing gear.

349. The " Yarmouth " mooring and towing gear, shown in fig. 91, is the type which is generally used for boat seaplanes. This gear takes the form of a main central bridle and painter, and the towing bridle. The main bridle is made in two lengths, connected together by a shackle, with the ends attached to fittings on the bow and keel of the hull. The painter, which is connected to the bridle shackle, extends forward some feet to a second shackle, and to this the tow rope and side lines are attached. The two side lines composing the towing bridle run aft from the towing shackle to fittings generally situated on the lower centre section wing roots. This type of gear provides the greatest amount of security and freedom from yawing during towing operations.

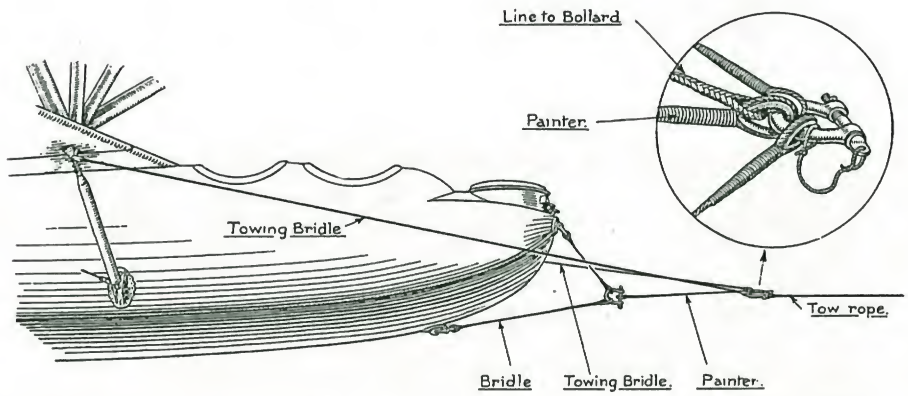

FIG. 91.—Mooring and towing gear.

Trollies, deck.

350. A special form of trolley is required for handling float seaplanes on aircraft carriers. The usual type is constructed with a wooden body and castoring wheels. The chocks, which are arranged on the top surface to give adequate supporting areas for the floats, have to be specially arranged to suit the type of float used. Some types of float planes have an axle incorporated in the floats, by means of which the floats are raised off the deck. This arrangement usually necessitates a special form of trolley.

Trolley, tail skid, scoop type.

351. A tail skid trolley is normally required for most deck-landing aircraft. One of the types of trolley used is shown at F, fig. 90. Other kinds are used, but they are, in most cases, peculiar to one type of aircraft.

Trestles, float. Stores Ref. 4A/336 (G. Stores 142) and 4A/473 (G. Stores 562).

352. A long, low trestle is needed for float seaplanes when in the shed or hangar. The type normally used is constructed in a similar manner to the ordinary fixed wooden trestle.

Trestles, docking.

353. During the repair and inspection of hulls, and similar operations, some means must be provided for supporting boat seaplanes at a reasonable height from the ground so as to allow sufficient room for working. The type of trestle used varies with the type of aircraft, but a trestle of the type shown in fig. 92 is generally employed.

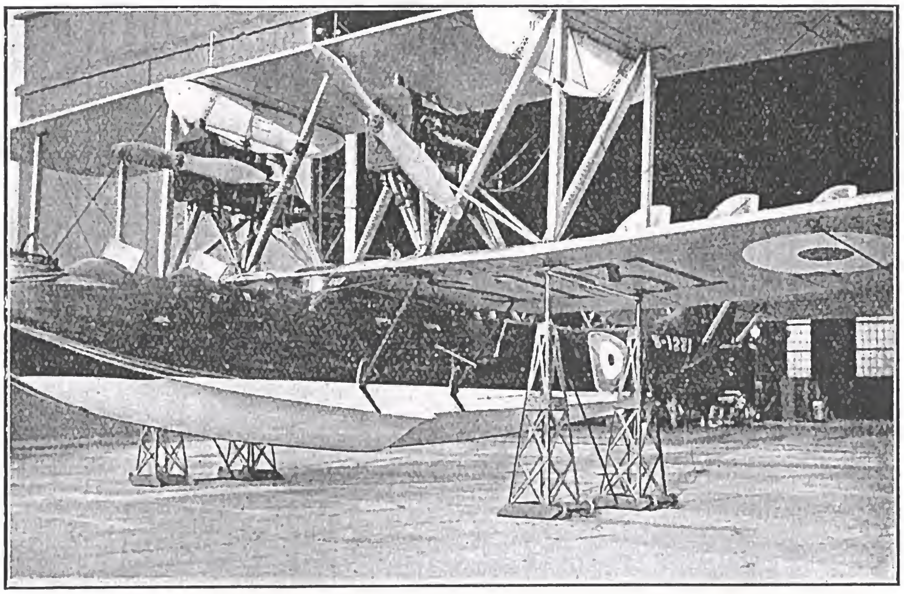

FIG. 92.—Boat seaplane. Jacking trestles in position.

354. For further details regarding particular aircraft reference should be made to the handbook of the type, and for the general conditions of handling and flying of seaplanes the R.A.F. Flying Training Manual, Part III, should be consulted.

CHAPTER XII.

BONDING, SCREENING AND EARTH SYSTEMS.

355. Bonding and screening is necessary in order to render an aeroplane suitable for wireless purposes and to prevent undesirable effects from static electricity. Screening is required for all actively electrified parts, such as magnetos and magneto leads and switches, and entails the enclosure of the various parts in an earthed metallic casing. The rigger has seldom to concern himself with this part of the system. The bonding and earthing system, on the other hand, should be thoroughly understood as, especially during repairs, the rigger will often need some knowledge of the systems employed.

356. The bonding and earthing systems are evolved on similar lines for each type of aircraft, and are incorporated to increase the effective electrostatic capacity of the aeroplane, as a necessary precaution against fire risk, and for the reduction of noises in the wireless receiver, owing to the intermittent contact of any loose metal members. Properly undertaken, the system ensures that all the metal parts of the structure are in good electrical contact and therefore at the same potential. For this reason, all the connections made are arranged to have a negligible electrical resistance. Every component which is bonded is marked in a conspicuous position with the letters " WT " enclosed in a diagonally divided square.

Bonding of wooden and composite aircraft.

357. On wooden and composite aircraft the earthing system consists of the main earth strip, feed wires and branch connections. The main earth strip is composed of a soft $\frac{1}{4}$ in. copper or brass strip between 26 and 30 S.W.G. in thickness. The main earth strip is fitted along each fuselage longeron, and soldered or otherwise attached to the metallic parts at the ends, such as the engine bearers and the stern-post. The strip is secured by small brass pins, 6 in. to 8 in. apart.

358. Each main plane is fitted with three 18 S.W.G. copper or brass feed wires, running parallel with one another, one along the leading edge and one along each spar. The outer ends of these wires are bridged across, either by means of the leading edge wire, which is left sufficiently long for the purpose, or, when the wing tip is of metal, by direct connection thereto by soldering if possible. The centre planes are treated in a similar manner.

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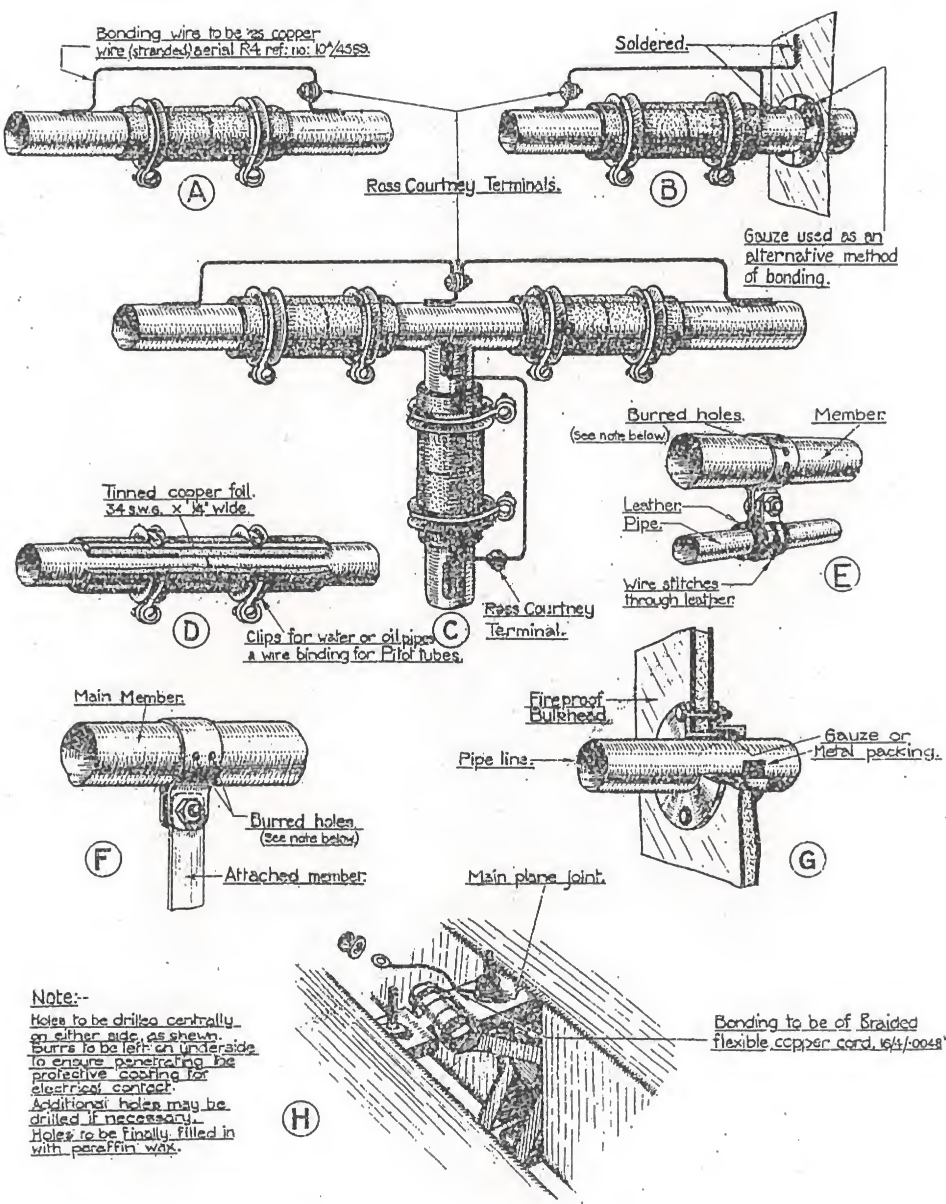

FIG.93 — METHODS OF BONDING.

P3682.

359. Tail planes, fins, rudders, have no feed wires, but all the internal metallic fittings are connected together by 18 S.W.G. copper or brass wires and so arranged that the whole system on each component is connected by a soldered joint to one of the fittings which is in direct electrical connection with the main earth system. All metal fittings are connected to either the main earth strip or the feed wires by branch connections made from similar wire to the feed wires. All connections are soldered wherever possible, but where soldering cannot be done, special clips or lugs are employed.

360. Hinged or detachable fittings are bridged across by means of flexible copper wires, as indicated at H, fig. 93. These wires are usually 7/25 bare stranded copper wire, similar to the Service wire known as R.4, but sometimes a braided flexible copper cord is used. The ordinary fixed, or the Ross-Courtney type of terminal is used as required.

361. All fuel and oil tanks, either in the fuselage or in the planes, are connected to either a feed wire or the main earth strip. The connections are made by means of a copper strip soldered to each end of the tanks and also to the feed wires or earth strip. In order to avoid breaking the joints when dismantling, a Ross-Courtney or similar type of terminal with a spring washer is provided.

362. Undercarriages are bonded with flexible detachable connections throughout to ensure a good electrical path of low resistance to the main earth system of the fuselage. Special precautions are taken at all points where intermittent vibratory contact is possible. Cross bracing wires are separated by distance pieces of a high grade vulcanised fibre similar in shape to those shown at A, B and C, fig. 83, for internal and D and E, fig. 83, for external wires.

363. All pipes connecting fuel, oil or water tanks are bonded and in direct electrical connection with the main earth system. On many existing aircraft, the pipe bonding is arranged as shown at A, B and C, fig. 93. The bonding wire used is generally the 7/25 stranded copper aerial wire (R.4), Ref. 10A/4589. As shown, the ends of the wires are soldered to the pipes on each side of the joint or connection, and a Ross-Courtney or similar type of terminal is used to render the pipes easily detachable. The flexible wires are normally made as short as possible, and when finished the wires stand clear of the flexible sleeves of the joints by approximately $\frac{1}{2}$ in. The wires are never wound round the pipes in the form of a helix or coil, as an inductive effect may be produced thereby and this should be avoided. Where pipes pass through the fireproof bulkhead, they are bonded as shown at B or G, fig. 93.

364. Exhaust pipes are also bonded at intervals not exceeding 4 ft. The bonding material is usually a length of the copper main earth strip connected at one end to a lug on the pipe, and at the other end by soldering on to the main earth strip, or a metal fitting in direct connection therewith. The bonding strip should be long enough to allow the heat to be dissipated by radiation before reaching the soldered joint. All joints in the exhaust pipe are similarly bonded by a short length of strip attached to lugs or screws provided on either side of the joint.

365. All large bodies of sheet metal such as fireproof bulkheads, cowlings, fairings or tanks must be bonded at each end, and also in between if the size warrants.

Bonding of all-metal aeroplanes.

366. In principle, the bonding of all-metal aeroplanes is the same as that for wooden aeroplanes. The framework of the all-metal aeroplane is utilised instead of the main earth strip and the feed wires. In order that this can be done successfully, all the joints between the metal parts must have a good metal-to-metal contact. Since, in many cases, a film of varnish or enamel is deliberately inserted between the faces of the metal parts to prevent as far as possible the corrosive effect of interaction between the metals, the only electrical connection made during the manufacture or assembly of the parts is by means of rivets or bolts which secure the joints. This form of joint, although mechanically sound, is not always sufficiently reliable for wireless purposes, as the resistance may vary very considerably. In addition, if there are any points of high resistance, there is always the risk of sparking across the surface of the metal parts during wireless transmission, which is not conducive to safety. The cleaning off of the protective coating between the faces of the metal parts is not permissible, as this would defeat the object for which it was employed; therefore, in many cases a system of bonding is incorporated. When bonding is required, the types of bonding materials used for metal aircraft are copper foil, brass gauze, and flexible braided copper wires. When a flexible bond is made, the bond is generally so arranged that it will withstand, without breaking, the constant vibration encountered under normal service conditions.

367. The cleaning of the protective covering from the outer metal surfaces of the various components where bonding joints occur, is permissible if it is imperative in order to obtain a sound electrical connection, but when the joint is completed it must be recoated with a suitable protective coating. Where, for the purpose of attachment, clips are

wrapped round a member, the arrangements shown at E and F, fig. 93, are used. As indicated, two or three small holes are drilled through the clip, care being taken not to damage or clean off the burrs, which are used to pierce the protective covering of the member. At all detachable joints such as between the outer and centre planes, a removable metal bond is sometimes provided of the type shown at H, fig. 93. The flexible bridging connections must not be stretched too tight, nor yet be loose enough to make intermittent contact with neighbouring parts. It is essential that all bonding connections should make a good electrical connection with the main members on either side of the bonded joint, and that intermittent vibratory contact is avoided. Pipe joints are bonded by the insertion of strips of copper foil under the clips and also under the hose connection as indicated at D, fig. 93.

Soldered joints.

368. It is essential that when a soldered bonding joint has been broken for any purpose, great care and attention is given when re-making the connection. The main consideration is that all metal parts should be brought into permanent connection with the main earthing system. Therefore, positive electrical contacts must be made, as otherwise considerable masses of metal may be isolated or imperfectly connected.

369. All soldered joints must be positive, and every care must be taken to ensure this. It is not sufficient to place a blob of solder between the fitting and strip or wire, but each must be first tinned and the joint made by sweating up. The flux to be used when soldering should be resin or methylated spirit and resin, and immediately after a joint has been made all traces of the flux must be removed and the joints painted over with bituminous paint to prevent any possibility of corrosion.

Tests.

370. The normal method of testing a bonded aeroplane is to use a Wheatstone bridge or similar instrument, and, after deducting the resistance of the external wires used for connecting up the instrument to the aeroplane, the resistance observed should not exceed 0·025 ohm when contact is made between the points enumerated below :—

(i) Between the extremities of all main horizontal members of the fuselage.

(ii) Between the main spars and the leading and trailing edges and the selected ribs.

(iii) Between the two vertical and cross members of the fuselage.

(iv) Between the axle and the undercarriage supporting members.

(v) Between all bracing wires in the locality of the wireless compartment.

(vi) Between all interplane struts.

(vii) Between the fireproof bulkhead and all metal cowlings, fairings, and panels.

371. When a Wheatstone bridge or a like instrument is not available, a ready means of testing the electrical continuity of the aeroplane generally is provided by utilising a 2-volt accumulator and a standard 2·5-volt minature lamp. A 500-volt " megger " should not be used. The 2-volt lamp tester consists of a short flexible lead composed of an ordinary twin flex wire, with the bared ends twisted together, which is run from one terminal of the accumulator to the wireless earth terminal, and another length of similar flexible wire long enough to reach the most distant parts of the aeroplane (and thus form a wandering lead) is connected to the other accumulator terminal. At the outer end of the long wandering lead is attached a miniature lamp-holder and a sharp metal spike, connected in series. The spike is required to make contact with the various metal parts by piercing the enamel or other protective covering, but in so doing cause as little damage as possible.

372. The spike and lamp are conveniently made up in one unit by employing a large-sized file handle, screwing on a batten type miniature lamp-holder near the ferrule, and inserting a steel spike in place of the file heft. The wandering lead is connected to one terminal of the lamp-holder and the spike to the other.

373. Before testing, make a contact directly between the spike and the wireless earth terminal, and note the brilliancy of the lamp ; then proceed with the testing by pressing the point of the steel spike firmly against the metal portions of the aeroplane. Under normal conditions the lamp should glow at practically the same brilliancy as when directly connected to the earth terminal. Should the glow of the test lamp diminish perceptibly, then an appreciable added resistance is indicated. When the lamp shows no light, then an isolated area is indicated. To ensure that no mistake has been made, the test should be repeated two or three times, and the lamp tested by making contact with the earth terminal.

374. The limits of the isolated area may be defined by making contact with the surrounding parts. If this is not

successful, the lead to the wireless earth terminal should be disconnected and attached to a second spike; then, with the first spike making contact with the isolated part, contact should be made with the second spike at various points surrounding the first spike until the cause of the resistance or break in the bonding has been ascertained.

375. A more accurate method of determining the resistance of joints, in default of specialised measuring instruments, is to pass a small steady current of known value through the portion to be tested, and measure the voltage drop with a sensitive milli-voltmeter. The resistance is then found by dividing the voltage drop by the current. If the circuit is

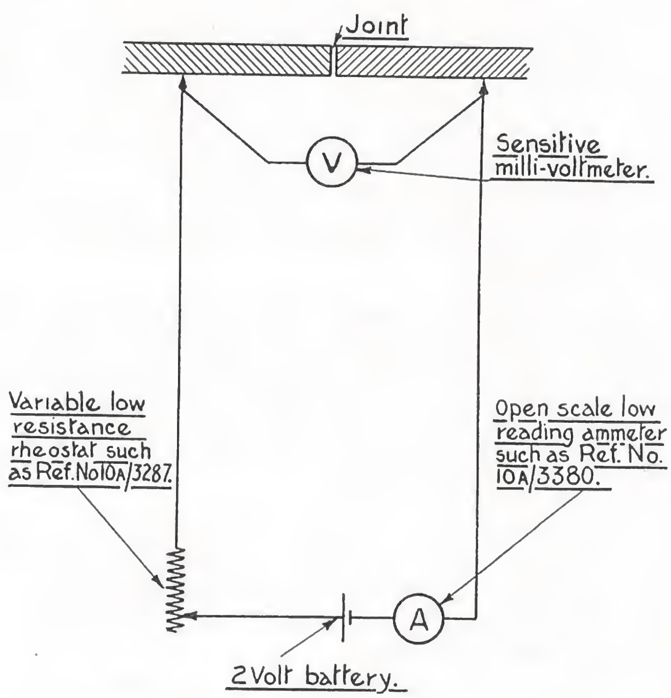

FIG. 94.—Diagram of connections for resistance tester.

arranged as shown in fig. 94 and the current is limited by an external variable resistance to one ampere, then the voltmeter will read directly in ohms, because the resistance $= \frac{\text{Voltage}}{\text{Amperage}}$, and, as we know the current passing to be one ampere, then the resistance $= \frac{\text{Voltage.}}{\text{Unity}}$

376. When tests are made across any single joint, the resistance observed should not exceed 0·05 ohm.

CHAPTER XIII.

REPAIRS AND MAINTENANCE.

377. After an aeroplane has been assembled and flown, there are manifold duties connected with the maintenance of the aeroplane in a sound and airworthy condition. This entails a regular and systematic examination of all parts, as laid down in Air Ministry Weekly Order 25 of 1929 and K.R. & A.C.I., para. 702, with the consequence that adjustments and minor repairs are found necessary from time to time, quite apart from the repairs necessitated by a more or less serious mishap to the aeroplane such as might be occasioned by a forced landing. If an aeroplane is seriously damaged, but not sufficiently for it to be struck off charge, it is usual to strip the aeroplane completely, dismantle the damaged portion, substitute complete components for those badly damaged, and repair the parts which are only slightly injured. The repair and maintenance notes for the type usually specify the limit of repairable damage, and the details provided generally cover all normal eventualities. The repair and maintenance notes are either issued separately or incorporated in the aeroplane handbook.

378. The methods of repair vary in accordance with the type of construction used, and it is obvious that a repair which is suitable for one type of aeroplane will in most cases not be suitable for another type. It is highly important, therefore, that only those repairs should be used which have been approved for the particular type of aircraft, and which are enumerated in the repair notes.

379. Before repairs can be undertaken, it is usually necessary to have certain special tools which are required for the particular type of riveting or jointing employed. These tools, in addition to any jigs and special materials required, are normally available for the unit.

380. Whenever it can be arranged, approved repairs are made with patches which are cut and drilled ready for use. In certain instances, such as leading and trailing edge tubes, lengths of materials are supplied which have to be cut to the correct length and bent to the required curvature.

381. Before any attempt is made to repair a damaged structure, it is advisable to classify definitely the repair as replaceable, repairable or negligible. The repair notes usually define the limits of any of the three classifications.

382. The repairs normally undertaken by units do not entail any complicated processes, and the following paragraphs provide general comments for the information of those concerned.

Removal of rivets.

383. In many instances the repair is effected by cutting out the damaged part, extracting the old rivets and putting on some form of patch which utilises to some extent the old rivet holes. Great care must therefore be taken when extracting rivets not to damage or loosen the neighbouring parts. The method employed for extracting the rivets depends upon the type of rivet used.

384. For solid rivets the normal method is to file a flat on the head and drill the head, using a drill somewhat larger than the diameter of the rivet. The hole is carried to a depth a little less than the depth of the head. The head is then chiselled off, using a dolly to support the rivet on the reverse side. A small pin punch can be used to tap out the shank of the rivet, but if difficulty is experienced in extracting rivets, they should be drilled out. Excessive force should not be used in punching out. Tubular rivets should be drilled out, using a drill of the same size as the rivet to be removed, or a small countersunk rose cutter. The shank is then tapped out, using a pin punch or a piece of tube of the same diameter as the rivet being removed. Pierced and cup rivets should be extracted in a similar manner.

Renewal of rivets.

385. There will be occasions when rivet holes will have become enlarged owing to either the usage in service or to the faulty extraction of the rivet. In these circumstances, it is permissible on some aircraft to use a size larger rivet, and drill out the hole to suit. Unless definite instructions are issued to the contrary, new holes should be drilled and not punched, as punching reduces the strength of the material in the neighbourhood of the hole. Riveted joints should be so made that there is no possibility of movement between the faces of the parts joined. If working should take place, there is a strong probability of wear which results in elongation of holes and reduction in cross-sectional area of the rivets; therefore, when drilling a new hole for a rivet it is important that the correct size of drill should be used, and also that the correct amount of rivet should protrude through the hole for purposes of riveting over. All the essential information in this respect is usually included in the aircraft repair notes. If the manufacturers' limits are known, they should be followed, but the following information is given as a guide, should precise instructions not be available.

386. The exact diameter of the holes for solid mild steel rivets is not of great importance, because the shanks of the rivets expand during riveting and fill the hole, but the

smallest size of hole convenient for working should be used, giving no more than, say, about $\frac{1}{64}$ in. clearance for rivets of $\frac{1}{8}$ in. to $\frac{1}{4}$ in. diameters. Solid stainless steel rivets require a more closely fitting hole, as the rivets harden immediately riveting commences with a consequence that the shanks of the rivets do not swell very much. A clearance of about ·003 in. should be sufficient, and the sizes of drills which are recommended are Nos. 41, 30, 21 and 11 for rivets of $\frac{3}{32}$ in., $\frac{1}{8}$ in., $\frac{5}{32}$ in. and $\frac{3}{16}$ in. diameters respectively. The shanks of solid light alloy rivets swell considerably during riveting and a definite clearance of about ·01 in. is required when riveting light-alloy plates, as otherwise a wavy or puckered surface is produced owing to the spreading of the material round the holes. Suitable sizes of drills are Nos. 37, 29, 19 and 8 for rivets of $\frac{3}{32}$ in., $\frac{1}{8}$ in., $\frac{5}{32}$ in. and $\frac{3}{16}$ in. diameters respectively. Tubular and pierced rivets should be a close fit in the holes, as the shanks are not definitely expanded as in solid rivets. It is advisable to ream the holes for tubular rivets if high stresses are likely, but if the rivet is not heavily loaded the holes should be drilled with about ·003 in. clearance, using about the same size of drill as is recommended for stainless steel rivets. When ferrules are not provided and the materials or fittings allow of the operation, specially for steel, the edges of the holes for tubular rivets should be slightly cut away to allow a small radius to be formed when turning over the head.

387. The riveting allowance necessary for forming snap heads on solid rivets when riveting thin materials with a hammer and snap, is about $1\frac{1}{4}$ to $1\frac{3}{4}$ times the diameter, the amount depending upon the hardness of the rivet and the clearance given, the larger allowance being used for the softer rivets. An allowance of about $\frac{3}{4}$ the rivet diameter is necessary for countersunk rivets. A greater allowance is sometimes made when the riveting is done with special tools, and when the materials being riveted are comparatively thick. As an instance, the allowance for snap head light-alloy rivets, when hand riveting materials with a total thickness equal to not more than the diameter of the rivet and using the clearances given above, is about $1\frac{1}{4}$ times the diameter of the rivet. When the materials being riveted together have a greater total thickness than the diameter of the rivet, then an additional allowance may be given of approximately ·03 in. for each $\frac{1}{16}$ in. increase in thickness. For tubular rivets practice varies widely, but for small sizes and for normal gauges of tube wall thickness, say between 20 g. and 24 g., when hand-riveting with a snap and dolly, an allowance equal to not more than half the diameter can be given. This should be sufficient to form a good head and avoid cracking at the lip. When a

spinning tool is used, the amount left for riveting over can be greater, and an allowance equal to $\frac{3}{4}$ the diameter of the rivet should not be excessive. When the special snaps and dollies are not available, the rivet should first be opened out with a 60° punch and the edge peaned over with light hammer blows.

388. The types of rivets employed vary considerably both in material and shape. Fig. 95 indicates the shapes of rivets normally used for aircraft construction, type A being more used than the remainder. Rivets A, B and C can be

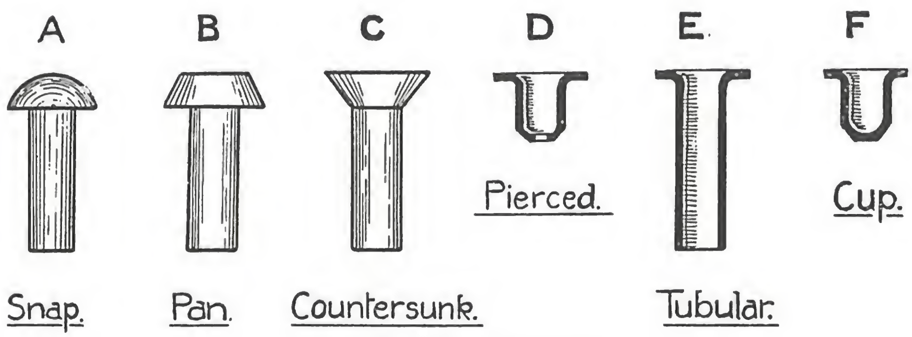

FIG. 95.—Types of rivets.

riveted over with a hammer, dolly and snap or any of the usual methods, but rivets D, E and F generally require some form of special punch or tool to form the head correctly, as the metal is not spread as in the solid type but is merely bent or spun over.

389. Riveted joints are made in several ways, depending mainly upon the strength and purpose for which the joint is required. The types of joint used are lap and butt, the latter having cover plates on one side or both. The types of riveting used are single, double, treble or quadruple according to the number of rows of rivets, and the rivets may have a chain or zigzag formation. Fig. 96 indicates the types of joints and the forms of riveting.

Bolt holes.

390. Unless it is to be subsequently reamed, it is usual to drill a hole slightly larger than the diameter of the bolt to be used, in order to allow for any small inaccuracies in the position of the hole or slight variations in the size of bolt. The clearance which is allowed for bolts in unimportant work is $\frac{1}{32}$ in. for all sizes above $\frac{1}{4}$ in. diameter and $\frac{1}{64}$ in. for this size and smaller sizes. This provides an easy fit for the bolts in all circumstances, but does not require exceedingly accurate workmanship.

391. When repairing aircraft the sizes of all bolt holes required are usually stated in the aircraft repair notes. In the absence of any definite instructions, it is advisable to fit all bolts, that is, the holes are drilled slightly smaller than is finally required and then reamed to obtain a good fit for the bolt. If a reamer of the correct size is not available, it is often possible to obtain a well fitting bolt by using a drill of the same size as the nominal diameter of the bolt and selecting a bolt which will fit the hole. This is possible owing to the minus manufacturing limits on the bolts, and the fact that holes drilled by hand in thin materials are usually larger by a few thousandths than the size of drill being used.

Cutting lubricants.

392. When drilling and tapping holes it will be found that certain materials are difficult to work unless some form of lubricant is used. The use of a lubricant is not so important for hand work as it is for machine work, but even for hand work its use is advised as it assists in keeping the edges on the tools by reducing the heat generated, and is also of great assistance in preventing the sticking or digging in, which is a prolific cause of broken drills and taps. The compounds used vary to some extent, a soluble oil, Stores Ref. 34B/100, is available for general machine work, but in the absence of this substance or of any definite instructions, the compounds given below can be recommended. Care must be taken to avoid the generation of excessive heat when using inflammable lubricants.

TABLE VI.

Material.	Hand working.	Machine working.	Proportions.
High tensile steels.	Turpentine or paraffin.	Borax, lard oil and water.	15 oz. Borax, 1 gal. lard oil to 4 gals. water.
Ordinary steels.	Oil	Carbonate of soda, lard oil or soft soap and water.	1 lb. soda, 1 qrt. lard oil or soft soap to 10 gals. water.
Light alloys	Paraffin ..	Paraffin	—
Brass ..	None ..	None	—
Copper ..	Soft soap ..	Lard oil and turpentine.	Equal.
Cast iron ..	None ..	None	—

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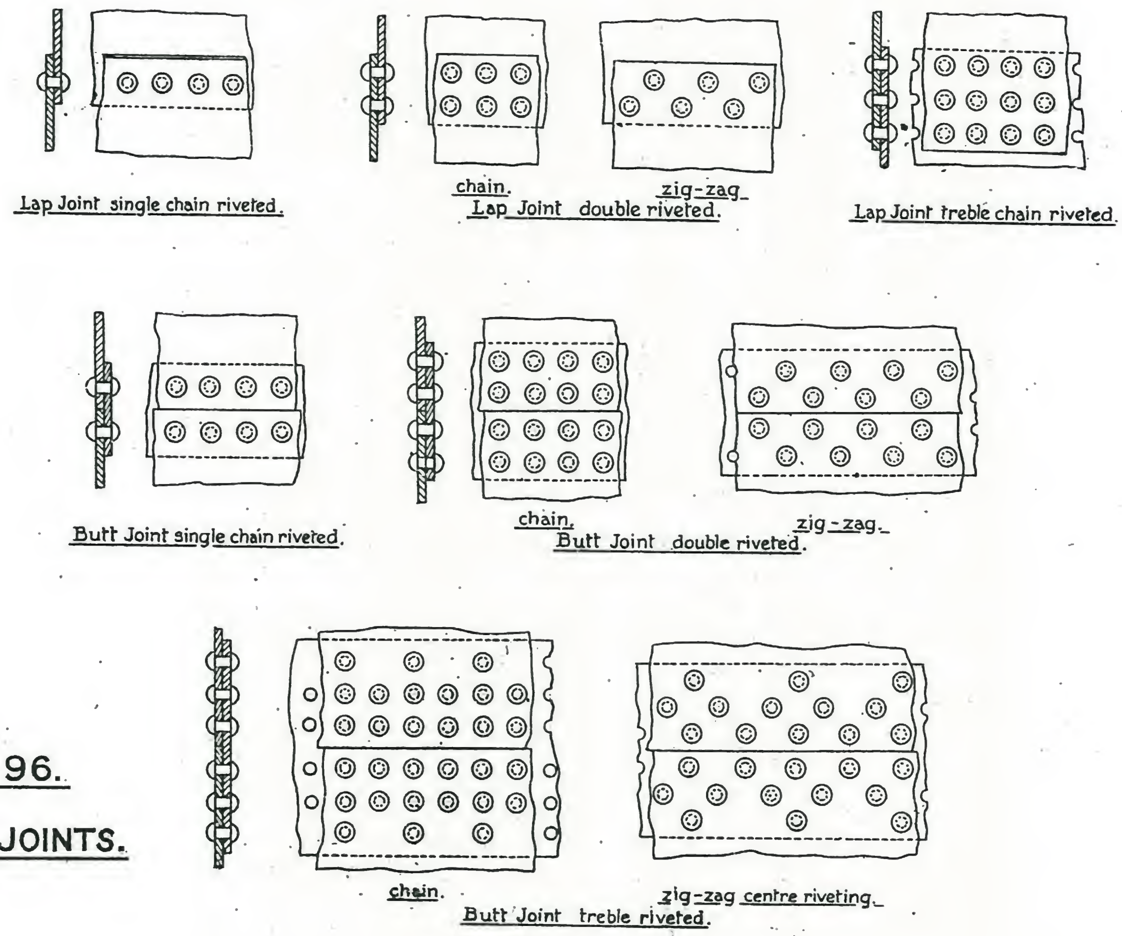

FIG. 96.

RIVETED JOINTS.

P3882

Oxy-acetylene welding.

393. Oxy-acetylene welding is a method adopted for joining metals by raising them to such a temperature that the parts in contact will fuse and flow together. The heat required for this type of welding is intensely local in character, and is produced by means of high or low pressure blow pipes which are fed from a suitable source of oxygen and acetylene gases. Oxy-acetylene welding is a scientific trade, and cannot with success be undertaken by anyone until the necessary knowledge and skill have been acquired. A very thorough knowledge of the basic principles of welding is essential, in addition to a comprehensive understanding of the characteristics of the materials employed. The manual dexterity and skill required for handling the blow pipes and plant is not inconsiderable and can only be acquired with practice. The range of materials which can be welded by this process is very wide, but under Service conditions welding for aircraft is normally employed only for those parts composed of steel. Certain steels are more suitable than others for welding and should therefore be utilised whenever possible.

394. Experience has shown that certain high-tensile alloy steels should not be welded, as their full strength cannot be developed after welding by heat treatment or any other process. For other ferrous materials, where heat treatment after welding is possible, any of the suitable B.E.S.A. or D.T.D. Specifications can be used. Where heat treatment cannot be undertaken, then the materials which are suitable are limited for aircraft structures to S.3 Sheet, S.21 bar, T.26, D.T.D. 41, 89, 89A and 113 tubes. Preheating may be necessary, especially if a casting is being welded, but subsequent heat treatment is essential if the materials being used originally obtained their strength by this process. The heat treatment employed may consist of hardening and tempering, tempering only, annealing and normalizing. All parts expand and contract considerably during welding, and therefore precautions must be taken to avoid where possible the troubles which ensue due to distortion and cracks.

395. Fluxes are used for most materials, and it is essential that the correct flux should be used if welding is to be successful. Three fluxes are in normal use, one type for cast iron, one for aluminium and one for brass.

396. Under normal conditions it is usual when welding to use a rod or wire of suitable size and material as a filler. The material of which the rod or wire is composed is of course of primary importance, but care should be taken to see that the correct size of filler is used, as if it is too small, excessive

oxidation will occur and if it is too large, it will tend to chill the material at the weld.

397. The strength of a welded joint in tension can be assumed for aircraft purposes to be about 66 per cent. of that of the material before welding, and in compression about 75 per cent. to 100 per cent., depending on the circumstances in which it is used. All the welded joints are normally so arranged that the failure of any one joint will not involve collapse of the structure under load.

398. It is essential, if the quality of the welding is to be good, that the plant employed should be kept clean and in good order and should not have a capacity which is too small for the demands made upon it. Welding work should not be undertaken casually but should be well thought out, and adequate preparations made accordingly.

399. It is essential, when repairing aircraft parts by welding, that only material identical with that originally employed should be used, and only methods adopted which are enumerated in the repair notes of the particular type of aircraft. For further information on oxy-acetylene welding, reference should be made to the handbook "Oxy-acetylene Welding and Cutting," Air Publication 880, 2nd edition.

Brazing.

400. Besides welding, there are two methods of making joints entailing the fusing of metals—brazing and soldering. Brazing requires a much higher temperature than soldering, but gives a stronger joint ; as a rule it is only used for joining iron or steel parts together. The parts are prepared by a thorough cleaning, and the scratches so produced should lie in the same direction as the direction of flow of the spelter. Joints to be brazed should never be made a close fit, but due allowance must be made for the spelter to flow along the joint as otherwise air pockets may be formed.

401. The source of heat must produce a smokeless flame such as that of a paraffin brazing lamp (of ample size) or a gas blow pipe. An oxy-acetylene flame should not be used. The parts being brazed should be surrounded by pieces of coke or brick, in order to hold the heat. The spelter, which is normally a soft form of brass or copper with a comparatively low melting point, may be obtained in three forms, brass, granulated and strip, and copper. Stores Ref. 30B/285, 30B/286 and 30B/287 respectively. The first two types are used for general iron and steel work. Borax is used as a flux, and is crushed, mixed with water, then added to the spelter and applied

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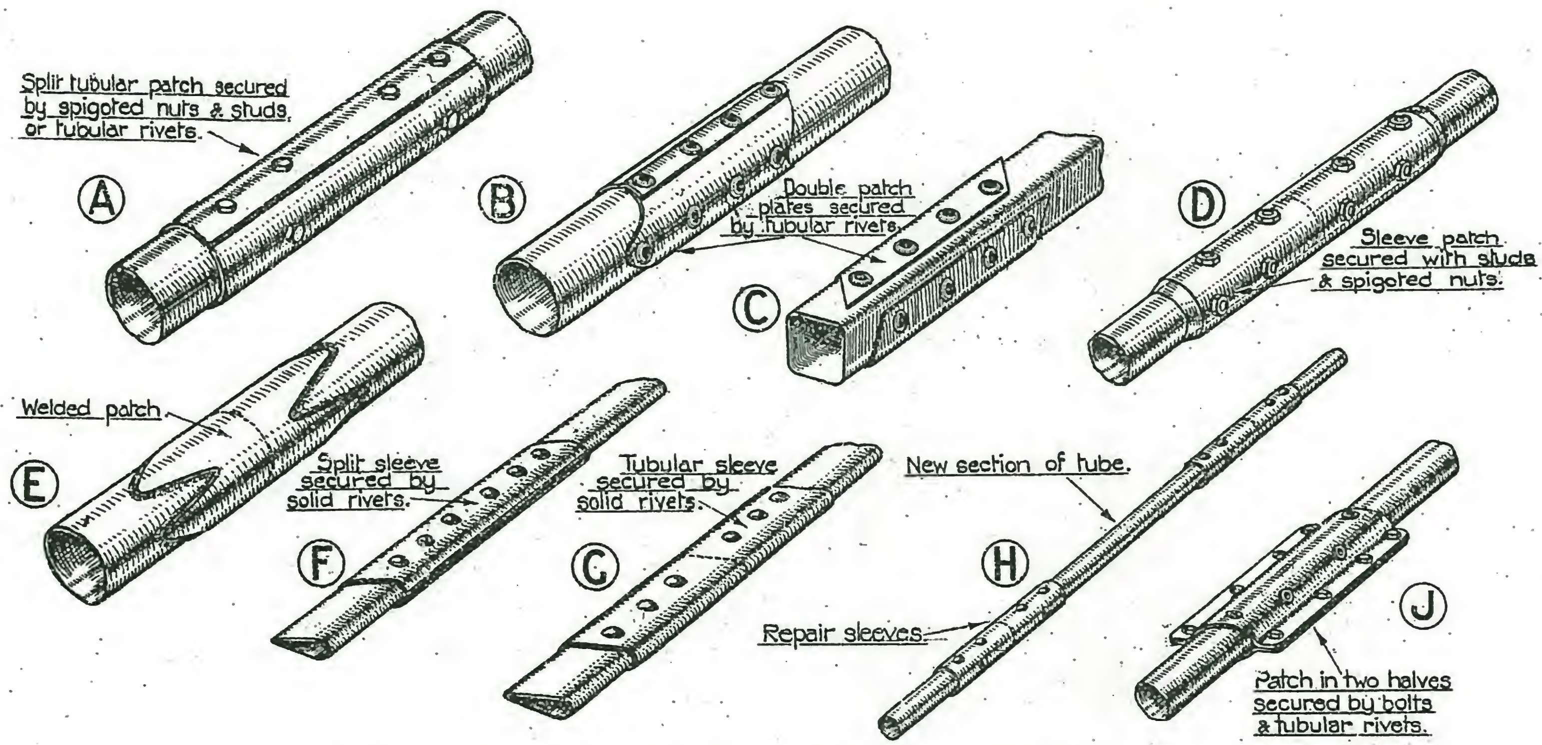

FIG. 97. REPAIRS TO SOLID DRAWN TUBES.

P3882.

as a paste to the parts to be joined. The flame is then played on the joint, gradually until the water has evaporated, then continuously until the spelter flows right into the joints. The spelter will not fuse until the parts are at a red heat.

402. Brazing can only be rarely applied to aircraft parts ; never to the high-tensile steels that obtain their strength by heat treatment or by working.

Soldering.

403. Soft soldering on aircraft structures is used in the attachment of tubes to end sockets and similar ways, generally in order to obtain additional stability at the joint. Three types of solder are supplied, plumber's, Stores Ref. 30B/282, silver, 30B/283 and electricians', 30B/545. The tinman's solder is used for all general work, the silver solder is used where a very strong joint is required, but where brazing would be inadvisable for the materials being joined. Electrician's solder has a resinous inset and is used for making electrical and other connections when the parts have been previously tinned or where the use of an ordinary flux would be inadvisable owing to its corrosive effect. The type of flux in general use is Fluxite, Stores Ref. 33C/244.

404. For successful soldering, it is necessary that the bit should be tinned and, unless an electric or other self-heating type is used, that it should be sufficiently heavy for the job. All parts to be soldered should be thoroughly cleaned and tinned before forming the joint, and sweated together. Care should be taken to employ a type of flux which has as little corrosive effect as possible, and all fluxes should be thoroughly cleaned off with petrol or hot water after a joint has been made. Silver solder is not frequently used, and the method of making a joint with this medium is similar to that employed for brazing. Joints formed by soldering only are not employed on aircraft structural members. Rivets, pins or bolts are always used in addition.

Repairs to solid drawn tubes.

405. Repairs to tubes can be effected by tubular sleeves, split sleeves or patch plates, and they are secured by riveting, bolting or welding, depending upon the type of construction used. When a tubular repair sleeve is used it can be internal, or external, as shown at D, fig. 97. In either case it is usual to serrate or turn down the ends of the tubular sleeve to avoid any sudden change in section. Care must be taken, when sliding on the sleeves, that the structure is not strained when separating the ends of the repaired tube where it is cut.

406. Split sleeves are applied externally in the manner shown at A, fig. 97. Patch plates are used for square or round tubes, and the methods of attachment are indicated at B, C and J, fig. 97. When a tube is so badly damaged that it is necessary to cut out a complete section, it is usual to replace the discarded portion by a length of tube similar in diameter, gauge and specification, and attached as shown at H, fig. 97. The tubes of welded structures can also be repaired by welding on patches arranged in a similar manner to that shown at E, fig. 97, but only when the original structure has been welded during assembly. Tubes which have a streamline shape, such as is used for leading and trailing edges, are repaired in much the same way as round tubes, that is, by using split sleeves or tubular sleeves of a suitable streamline shape, which are riveted into position as shown at F and G, fig. 97.

Strip steel repairs.

407. The normal method of repair of a strip steel structure is to rivet on a patch of special section strip steel which has been rolled or drawn to the section required. Built-up round tubes are repaired by the patch method shown at C, fig. 98, or by internal tubular sleeves as indicated at B, fig. 98. In both the instances shown, the type of repair is

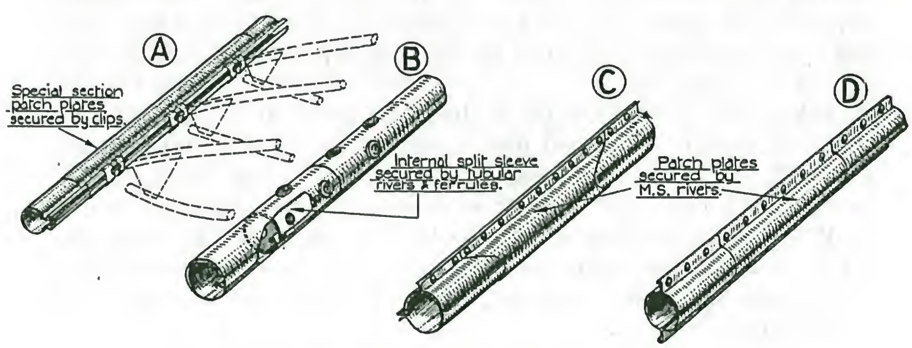

Fig. 98.—Repairs to strip steel tubes.

applicable if it has been found necessary to cut out a completely damaged section of the member, by elongating the repair material. Leading edge strips and similar sections are repairable, one method being indicated at A, fig. 98. Built-up strut sections are normally patched as shown at D, fig. 98.

408. As strip steel structures are built up with many varied sections, it is impossible to do more than indicate the types of repairs which are undertaken.

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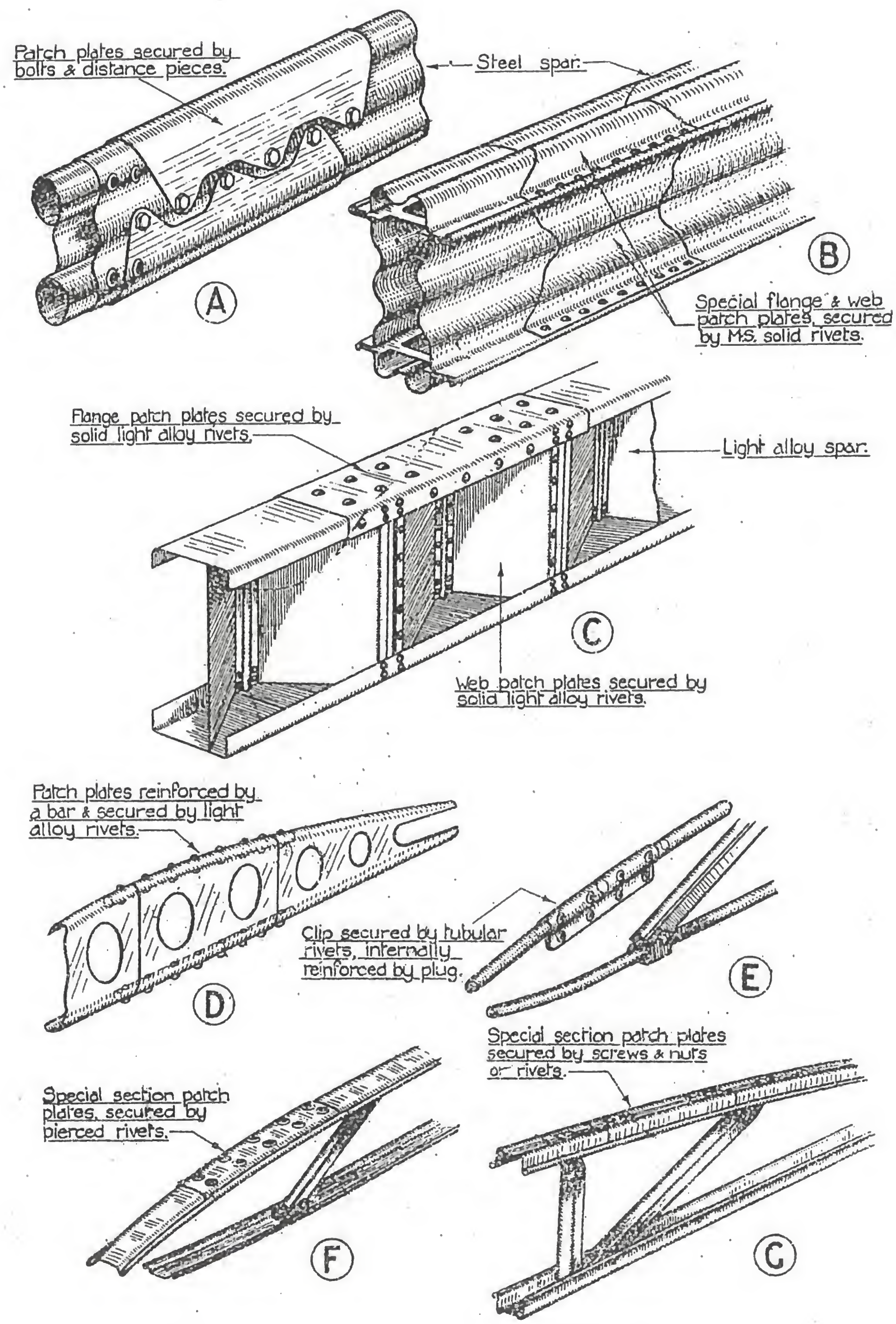


FIG 99. REPAIRS TO SPARS AND RIBS.

P 3862.

Spar repairs.

409. Most types of metal spars are repairable, but as these parts are the main strength members of the wings, considerable care is to be exercised to ensure reliability and truth of the member after repair. The method of repair is usually to rivet on rolled or drawn strips which conform to the shape of the flange or web, as shown at B and C, fig. 99.

410. Tubular spars are repaired in a similar manner to that employed for tubular struts, which has already been described. Special section tubular spars of the type illustrated at A, fig. 99, are repaired as indicated by patch plates of U-section, which are placed over the spar from above and below and riveted on to the spar at the neutral axis. Only those repairs authorised in the aircraft repair notes are to be attempted.

Ribs.

411. Unless the damage is slight, injured ribs are usually discarded and substituted by special replacement ribs. The method of repairing ribs depends greatly upon the type of construction, but in most cases it is effected by patch plates of suitably formed materials which are riveted over the damaged portion as shown at D, E, F and G, fig. 99.

Metal hull and float repairs.

412. Minor damage to the sections of metal hulls and floats is repaired by patch plates, which are riveted into position. The size and shape of the patches obviously depend upon the amount and position of the damage ; therefore, in most cases, the exact manner of repair can only be decided after examination. Repairs of metal hulls and floats are usually far simpler than the repair of equal damage to a similar wooden structure, and, if the repairs have been carried out correctly, there is generally no question whatever of any loss of strength. Except where extensive rebuilding is necessary, repairs should present no great difficulty, as the damage to metal structures is generally local in character. The method of repair should always follow as closely as possible the original method of construction.

413. When a hull or float is holed, it is not always essential to remove the complete plate, but a small patch can be riveted over the hole. All patch plates should be at least as thick as the plates being repaired. Where damage is more extensive and involves stringers, intercostals or formers, it is usual to cut out the members concerned and substitute members made up to suit. For quick repairs, small bolts can be used

instead of rivets. During repairs, it must be borne in mind that the frames, centre keel, side keelsons and intercostals are usually the most important parts of a hull, and on these members depend its shape and strength. The type of riveted joint used for the repair will normally be one of those shown in fig. 96, but the pitch and size of the rivets should be similar to those employed on the part of the structure to be repaired.

414. If it is necessary to extract rivets, they should be removed by cutting off the heads with a small sharp cold chisel and a light hammer, and punching out the shanks. When making holes for new rivets, they should be drilled and not punched, and holes which are unfair or not in alignment should not be drifted but should be drilled out and fitted with a larger rivet. As already explained in para. 386, the holes required for light alloy riveting should provide rather more clearance for the rivet than is necessary for steel riveting. Rivet holes should not be countersunk unless countersunk rivets are being used, but a countersinking tool may be employed for removing burrs. Either pan or snap-head rivets may be employed, but the snap-head type is generally used, and this type of head is usually formed when riveting up. Duralumin rivets must be softened before use by normalising, and riveted up within one hour of treatment.

415. All metallic surfaces in contact at a joint should be given a coat of approved protective substance such as an enamel, with a basis of tung oil varnish or cellulose, and the parts riveted up after the enamel has dried. Care should be taken during repairs not to damage the extremely thin anodic surface of aluminium alloys. After repairs to a hull or float, either internal or external, water tests should be made to ensure watertightness. For further information and details, reference should be made to " Notes on the repair of duralumin hulls and floats " provisional issue, October, 1928.

Protection against corrosion.

416. One of the greatest enemies of metal aircraft parts is corrosion. An infallible and everlasting remedy for corrosion which is of practical utility has yet to be found for the majority of ordinary metals. The greatest advance within recent years was the introduction of stainless steel. The use of this material, of which there are several varieties, appears to be a solution of many problems connected with corrosion. Materials used on aircraft which demand the greatest care from the aspect of corrosion are ordinary steels and light alloys. Steels by themselves do not corrode at a greater rate than many other metals, but as already pointed out in para. 166, on account of their greater tensile strength they

are generally used in much thinner gauges than other materials and are therefore more susceptible to deterioration owing to this cause. Light alloys which have a basis of aluminium or magnesium are inherently unstable metals, and, given an opportunity, will corrode very quickly. The corrosion which occurs in these materials is not always attributable to exterior causes, but it may be due to the interaction which occurs due to impurities in the metal. For both steels and light alloys, the basic principle of protection against corrosion is to exclude the air from contact with the metals. If, therefore, corrosion is to be avoided, it is imperative that the protective covering should remain intact, or if, owing to mishandling or Service usage, the protective covering has become damaged, it should be renewed immediately. The Air Ministry Technical Order dealing with this subject is 352 of 1930.

417. The types of corrosion which occur are surface corrosion and that due to interaction, and the forms in which it may become evident can be classified as surface, intercrystalline, and pitting. Surface corrosion is usually easily recognisable as a visible form of oxidation, which on steels appears as rust, on light alloys as white powder, and on copper alloys as green verdigris. Surface corrosion is mainly produced by external atmospheric conditions such as great humidity, and is very pronounced in the presence of sea air or sea water.

418. The intercrystalline and pitting forms of corrosion may also be due to the same cause, but are perhaps more noticeable when some kind of interaction is present, owing to surface contact between different types of metal, and sometimes even between metals of the same kind. The interaction which has been mentioned is electrolytic, that is, a minute difference of electrical potential is set up between the parts, or between the microscopic constituents of the metal, due to the presence of moisture and salts or acids, or other conducive circumstances. Intercrystalline corrosion in its early stages is not so easily recognisable, as it affects the internal structure of the material, but as surface corrosion or pitting usually accompanies intercrystalline corrosion, surface corrosion may sometimes be taken as an indication of the presence of intercrystalline corrosion. The effect of intercrystalline corrosion on light alloys is to deteriorate the material very quickly, and finally, although the material has the appearance of considerable body and a large proportion of its original strength, it can in many cases actually be broken up by hand pressure. Pitting is a form of corrosion which occurs mainly in small isolated areas, penetrates some distance into the material, and may in many instances be attributed to impurities in the material.

419. For ordinary steels the normal precautions against corrosion take the form of stove enamel, cellulose and air-drying enamels, of which the stove enamel is perhaps the best and most durable. As an additional precaution, which is very necessary in some instances, ordinary steel parts sometimes have an electro-deposited film of zinc or cadmium of the order of ·0005 in. (half a thousandth of an inch) thick. Non-corrosive steel parts which are properly made and heat-treated do not suffer from corrosion to any extent, except when used as exhaust manifolds or extension pipes, where the temperature has a very harmful effect.

420. Light alloys are very difficult to protect effectively, and even when the best means available are adopted a considerable amount of care is necessary if a long service life is to be attained. Aluminium alloys are protected by means of anodic oxidation process, which produces an adherent surface film of oxide which is capable of protecting the metal against corrosion to a considerable extent. The degree of protection is greatly enhanced by an additional covering, depending upon the conditions, of non-acid oil or grease, such as lanoline, or a lanoline basis preparation similar to D.T.D.121, or by a coat of a cellulose enamel similar to D.T.D.63 or a tung oil varnish. Magnesium alloys can be treated in several ways, the best being perhaps the chromate immersion treatment. This treatment produces a film on the metal in a similar manner to the film produced on aluminium alloys by the anodic treatment, but is much more frail and must be followed immediately by a protective covering such as D.T.D.121 as a temporary measure, or enamel when a more permanent covering is required. The use of the temporary corrosion preventative D.T.D.121 is not confined to light alloys, but can be used with advantage for any metals when a more permanent method cannot be employed, or is not necessary.

421. For seaplanes, in addition to the surface protective coverings, there are certain structural precautions which are usually taken. These precautions generally involve the use of non-corrosive steels wherever possible, and the avoidance of surface contact between metals which produce interaction. Surface contact between metal faces is prevented by interposing an insulating film of enamel or varnish. This does not of course entirely prevent interaction, as there is then a tendency towards an undesirable activity at attachment rivets or bolts, but if these are made of stainless steel, this effect is minimised. When ordinary steel fittings are attached to light alloy hulls and floats, it is necessary to take special care to avoid corrosion due to interaction. For this purpose, enamel-impregnated fabric is sometimes used, placed between the contact faces. For non-corrosive steel fittings the same

care is not required, but it is advisable to interpose a film of enamel to prevent direct contact. All mating surfaces, such as between riveted lap joints, should be coated with enamel, which is allowed to dry before riveting up.

422. The external protective covering for light-alloy hulls and floats normally consists of two coats of under coat enamel, Stores Ref. 33B/63, followed by one coat of V.85 (cellulose with added gums), Stores Ref. 33B/55, enamel, cellulose, marine. For internal use one coat of V.85 is all that is necessary, except at the cockpit positions when grey green cellulose enamel to Specification D.T.D.63, Stores Ref. 33B/50 and 51, is in general use. All seats, lockers and similar types of equipment are usually covered with clear varnish to Stores Ref. 33B/1. The flats (floorings) are painted with grey enamel, Stores Ref. 33A/62. Lanoline, D.T.D.121, or any non-acid grease which may be used to prevent corrosion is unsuitable for tropical conditions, as owing to the temperature encountered its effects are very temporary. Ordinary cellulose enamel also is not entirely satisfactory under these conditions, but tests are now being made with the cellulose enamel, D.T.D.63, which has an addition of an aluminium pigment and gums, which it is anticipated will satisfy most requirements.

Repair and maintenance of airscrews.

423. Airscrews are so designed that they will absorb, at the stated maximum revolutions per minute, the full horse-power output of the engines at the operational height of the aircraft. The airscrew design factor which mainly governs the R.P.M. of the engine, is the pitch or blade angle, and provided that the engine is running correctly and discounting the effects of atmospheric conditions, any persistent increase of R.P.M. observed could only be attributed to a decrease or flattening of this angle. Serious damage to wooden airscrews is seldom repairable, but minor defects in airscrews which are covered with cellulose lacquer can be repaired in the manner described in Air Ministry Technical Order 404 of 1929. Wooden airscrews may be reconditioned by re-tipping or re-finishing. The service life of airscrews may be lengthened considerably if minor damage to the cellulose covering is repaired as soon as it occurs. The airscrew need not be detached for this purpose. Damage to airscrews usually occurs when the engine is run up on the ground, and is caused by small stones and sand which are drawn into the airscrew disc. If the airscrew is flown after the film has been damaged, the timber may be worn away. If the erosion is slight, the damage can be repaired by the application of the required number of coats of cellulose lacquer, but if the timber is pitted to a depth of about $\frac{1}{16}$ in. or more, time will be saved by using plastic wood,

Stores Ref. 33A/336, as a filler before the final application of the cellulose lacquer.

424. The metal sheathing on wooden airscrews is not intended as a protection against mishandling. Therefore when an airscrew is detached from its hub it should not be stood on the tips of the blade, but should be laid flat or hung up on a peg.

425. When fitting a hub to a wooden airscrew, or an airscrew with a wooden boss, care should be taken to ensure that the hub flanges are tightened uniformly. This should be done by first lightly tightening opposite bolts in turn, and finally tightening all bolts in the same order. It is essential that the bolts securing the airscrew to the engine hub should be drawn up tightly. This is necessary because the drive from the engine is transmitted mainly by friction between the hub flanges and the airscrew boss. If the bolts are not drawn up tightly, a rapidly increasing slackness will develop in service which will probably result in broken hub bolts and other troubles. The tightness of bolts should be checked after the first ground run of the engine subsequent to the fitting of the airscrew, and afterwards from time to time.

426. Metal airscrews must be handled with care, especially when turning the engine over by hand, because the tips of the blades are comparatively thin and consequently the angular setting may be upset if roughly handled. Seriously damaged metal airscrews are seldom repairable by the unit, and any cracks, fractures, or other serious defects render the airscrew unserviceable. The protective covering of the hollow steel blades may be destroyed by the abrasive action of sand or dust ; therefore, to prevent corrosion, blades of this type should be treated with the temporary rust-preventive, D.T.D.121, Stores Ref. 33C/301, (*see* Air Ministry Technical Orders 235 of 1929 and 352 of 1930). It is not necessary to protect light-alloy airscrews against corrosion when in use.

427. The normal inspection and maintenance of airscrews is undertaken as detailed in the schedule of aircraft maintenance.

Checking airscrews.

428. Wooden airscrews are manufactured to tolerances on dimensions and blade angles which are as small as practicable. Airscrews of this type, however, are susceptible after construction to changes in pitch, track and balance owing to the effects of shrinkage of the timber. Such changes do not necessarily render an airscrew unserviceable unless performance is appreciably affected or unless excessive vibration is experienced.

429. In order to carry out a satisfactory check of the dimensions and blade angles of airscrews, it is necessary to have a surface table of adequate size together with special measuring apparatus. Owing to its weight, size and cost, such equipment is only available at certain stations, where such a check can be carried out if required. The apparatus required includes, besides a large surface table, a steel protractor, a scribing block carrying a dial micrometer gauge, and a pair of hollow conical adaptors. A steel spindle which is a sliding fit in the bore of the adaptors is mounted on a base block so as to stand truly perpendicular to the table. The airscrew is lightly tightened down on to the spindle, rear face uppermost, with the adaptors arranged at top and bottom of the bore so as to bring the bore exactly parallel to the spindle. The surface table will then be at right angles to the bore and will constitute the datum line from which the various measurements are taken. The checks consist of measuring, by the usual methods employed in inspection rooms, all measurements given on the airscrew drawings, which must be available before this work can be carried out. In this connection attention is drawn to Appendix III, which gives possible extensions of tolerances on blade angles for wooden airscrews now in service,

430. The balance of an airscrew, however, can be easily checked by means of a simple form of balancing machine, Stores Ref. 4A/419. This machine takes the form of a rocking beam, pivoted upon hardened steel knife edges and supported in a frame of the wall bracket type. The beam has an overhung spindle rigidly connected to it for the reception of the airscrew, and mandrils fitting this spindle are supplied having outside diameters to accommodate different sizes of airscrew bores. The beam is cast with an I-section, approximately 17 in. by 5 in. in side view, with 3 rectangular apertures in the web. There is an upper knife edge in the front aperture and an upper and lower knife edge in the rear aperture. Owing to the overhung spindle, the weight of the airscrew gives a down-load on the front knife edge and an up-load at the lower knife edge at the rear. With the airscrew removed, the weight of the rear end of the beam is taken on the upper knife edge. As a slight amount of play has been arranged between the two rear knife edges, care must be taken not to damage them by any sudden application of load. The motion of the beam is damped by an adjustable oil dash-pot situated at the rear end of the frame. The rocking beam is capable of being locked in a vertical position by means of a sliding block attached to the frame, and has a pointer attached to its upper flange which indicates on a graduated scale the number of inch ozs. the airscrew is out of balance. When setting up the machine, the frame must be correctly levelled by means of the spirit level provided.

431. The beam must be initially adjusted to ensure that, with no load, the pointer is at zero. This adjustment is made by rotating the central screwed spindle of the traversing weight situated in the central aperture of the beam. In use, the beam is locked and the airscrew to be checked is assembled on the spindle by means of suitable mandrils, one at each end of the bore. Airscrews should be tested for balance with the blades of the airscrew in both the horizontal and the vertical positions. The balance of a wooden airscrew can be corrected, if the error is not large, by the application at advantageous positions of partial coats of the particular protective film employed. If the balance of the airscrew is such that it cannot be corrected by a few applications of the protective film, then the airscrew should be returned to stores depot for correction or rejection.

432. No attempt should be made to correct metal airscrews found to be out of balance, particularly those with interchangeable detachable blades. With such airscrews, moreover, opposite blades may in some instances, be found to differ slightly in length and track. Small differences of this nature are allowed in manufacture for the purpose of obtaining satisfactory balance and must not, therefore, be regarded as necessarily rendering airscrews of this type unsuitable for use.

433. The following method of testing an airscrew when fitted to an aeroplane is not a reliable method of checking the track of the airscrew but does give some indication whether an airscrew is badly out of truth or has been unevenly bedded on to the airscrew shaft by the tightening of the bolts through the airscrew boss. A trestle or other support is placed in such a position that it is a little in front of the path of the airscrew blades and level with a point about two-thirds along the blade away from the boss. The distance between the leading edge of the blade and some fixed point on the trestle is then measured for each blade, care being taken that all measurements are made in the same straight line, which should be approximately parallel to the airscrew shaft. For airscrews of about 8 ft. diameter the variations should be within ·25 in. Great care must be taken throughout to eliminate error due to fore-and-aft (axial) movement of the whole airscrew during turning.

CHAPTER XIV.

PRACTICAL INFORMATION FOR RIGGERS.

Accuracy of measurements.

434. Strictly speaking, it is not possible to determine the exact measurement of an object. A measurement by visual comparison can be made by means of a steel rule or tape to within, say, $\frac{1}{100}$ part of an inch. Greater accuracy than this cannot usually be relied upon, because of practical difficulties, and also because rules and tapes are themselves not made absolutely accurate. A vernier or micrometer caliper will measure to within 1/1,000 part of an inch (·001 in.), as explained in paras. 48 to 52, and micrometers can sometimes be read to an even finer degree, but dead accuracy is impossible, because even if the true length of the part could be measured, the length of both the part and the measuring instrument vary with every change of temperature. But a dimension or part can be measured to any reasonable degree of accuracy, and where it is of importance the accuracy required is usually stated, generally in the form of a " limit " or " tolerance," such as plus or minus two thousandths of an inch (written $\pm$ ·002 in.), which permits the part to be a little larger or a little smaller than the nominal size.

435. This means, that if, say, 20 parts go to make up a component, each of which have a limit of $\pm$ ·002 in., it is possible that the overall size of the completed article could be larger or smaller than the nominal size by ·04 in., or a little more than 1/32 in.

This principle applies to some extent to all aeroplane parts, but the individual limits are so arranged that the resulting accumulative error is not harmful.

436. The accuracy required generally varies with the length measured and the nature of the service required of the part. As an instance, engine parts are often measured to $\pm$ ·0005 in., whereas the span of a twin-engined bombing aeroplane is sufficiently accurate if it is correct to within the nearest $\frac{1}{2}$ in. The important point is that the rigger must be extremely careful in his measurements, realising that error—admittedly unavoidable—must be confined to a certain definite maximum. For this reason it is occasionally necessary to take the average of three independent measurements.

Plumb lines.

437. An improvised plumbline can satisfactorily be made from a length of fine cord and a piece of metal a few ounces in weight, say a short bolt or a nut. So long as one edge of the cord is used as the reference line, the absence of a point on the plumb-bob directly under the plumbline is immaterial.

Methods of determining right angles.

438. One of the necessities of rigging is some test of perpendicularity. It should be understood that in its geometrical sense (as used in this manual) the term "perpendicular" means "at right angles," and that one straight line which is perpendicular to another straight line may point in any direction so long as the angles at the point of intersection of the two lines are right angles (90°). The largest square usually available is about 10 in. long in the blade. This tool is indispensable for the rigger, but it is of little use when dealing with large dimensions. There are, however, several simple methods of ascertaining whether two lines or parts are at right angles.

439. One method is to mark off three units of length as large as convenient along one of the parts, and four of the same units along a second part. If the lines are at 90°, a line drawn between the outer marks (thus forming a triangle) will be equal to five of the units in length, as shown at B fig. 100.

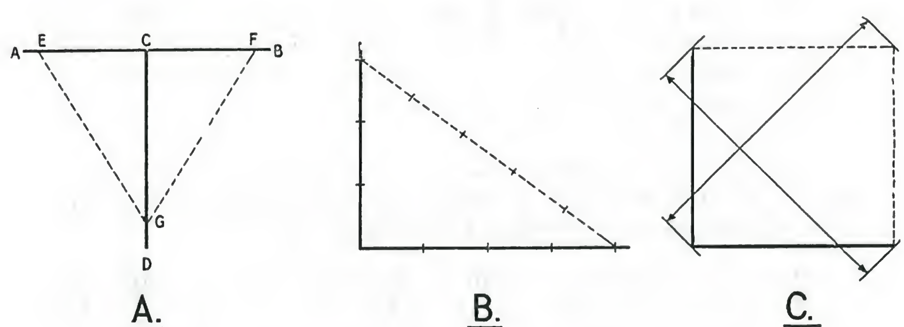


FIG. 100.—Methods of determining right angles.

440. Another method is shown at A, fig. 100. In this example it is desired to test whether AB and CD are at right angles. It is necessary to take two points on the line AB, which are equi-distant from C, say E and F. Then take a point G along the line CD and compare the distance GE, GF.

If the measurements correspond, the angles ACD and BCD are equal and if the lines AB and CD are straight, the angles will be right angles.

441. A third method of testing whether two lines are at right angles is as follows. Measure equal distances along each line, and using the same dimension, complete with square by marking the fourth corner, thus making a parallelogram with all four sides equal in length. Then measure the diagonals. When all four sides are equal and the diagonals are equal, adjacent lines will be at right angles to one another as shown at C, fig. 100.

Testing straightedges.

442. Straightedges can be roughly checked by sighting along the edges or placing two straightedges edge to edge and ascertaining by holding up to the light if there are any gaps. If greater accuracy is required, the straightedge should be placed on a surface plate and the truth checked by using feelers and a dial gauge.

Testing spirit levels.

443. Place the spirit level on any flat surface, such as a surface plate or a straightedge. Note, or mark, the position of the bubble and the position of the ends of the level. Now turn the level so that its ends are reversed, but the level occupies the same position as before. If the surface on which the spirit level is placed is truly horizontal and the level is accurate, the bubble will be central in both positions. If the surface is slightly inclined, the bubble should be in the same relative position in each case.

Testing a square.

444. To test a square obtain a piece of board which has a true edge. Then, placing the square in the normal manner against the true edge, draw a pencil line on the board using the blade of the square to obtain a line at right angles to the board. Then turn the square over and bring the edge of the blade up to the pencil line, the opposite face of the blade then being in contact with the board. If the square is true, the edge of the blade will be parallel to the pencil line.

Tie-rod holders and spanners.

445. When adjusting or locking the bracing wires of an aeroplane, care must be taken not to employ too much force, as by so doing a wire or the nuts may be damaged. With

these objects in view, the rigger is supplied with a fixed spanner in the form of a disc, $1\frac{5}{8}$ in. in diameter, as shown at C, fig. 101. This spanner has three slots round its periphery which are suitable for the smaller sizes of nuts. At A and D, fig. 101, are shown types of spanners which some riggers make up for themselves, but if spanners of this type are used, the tightening must be effected with discretion, as the leverage obtainable is sufficient to strip the threads.

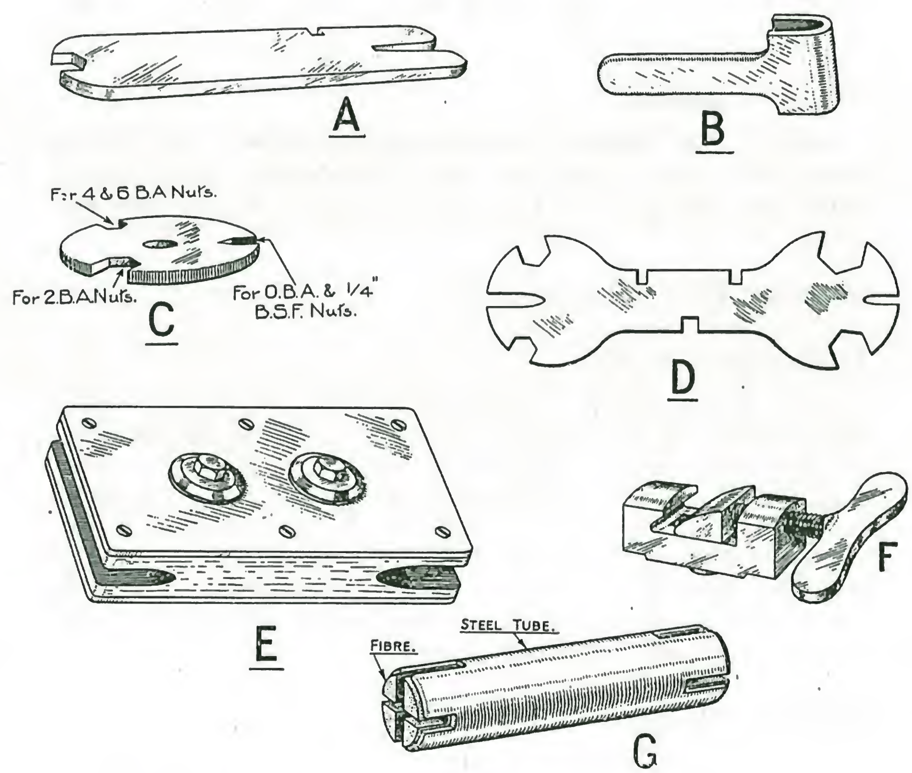


Fig. 101.—Spanners and wire holders.

446. During adjustment and locking, a streamline wire must be held as close as possible to the threaded portion and the whole wire turned bodily, without twisting it, if possible. The tool shown at F, fig. 101, is useful for this purpose, but does not form a part of the riggers standard tool kit. The tools shown at B and E, fig. 101, are additional types of wire holders which can be made up if desired. The ordinary adjustable spanner can, of course, also be used for the same purpose. Pliers of any sort should not be used to hold wires or to tighten nuts.

Telescopic Trammels.

447. A form of trammel which is especially useful in measuring or checking the distance between two points which are so placed as to make the use of one of the ordinary beam type difficult, may be easily made from materials to be found in any workshop. A length of tube of about $\frac{1}{4}$ or $\frac{3}{8}$ in. inside diameter has a pointed piece of rod inserted at one end, where it is brazed or soldered into the tube. A length of rod, of a diameter which allows it to slide freely within the tube, is then inserted at the open end and pushed home until

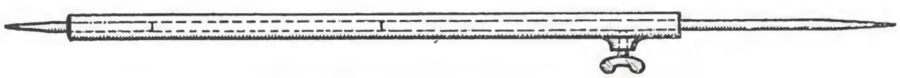


FIG. 102.—Telescopic trammel.

it meets the end of the fixed piece. The long piece is then cut to length with about 1 in. projecting beyond the end of the tube, this end being ground to a point similar to that of the fixed end. A pinching screw passing through the wall of the tube is used to secure the adjustable portion of the trammel when the points are at the required distance apart. The screwed hole to take this may be tapped directly into the wall of the tube, if this is thick enough, or it may be necessary to braze on a small boss to take the screw. Fig. 102 shows a typical trammel of this type.

Loop splicing of steel cables.

448. It is occasionally necessary to splice flexible steel cables, and the usual method adopted is shown in fig. 103. As will be seen by reference to the illustration, the cable is first served with waxed thread in two positions to prevent unnecessary unwinding of the cable. The cable is then bent in the form of a loop, and if a thimble is to be used it is then placed in position. Strands of the cable are next loosened by twisting and using a marline spike, and the separated strands at the end are tucked under and over the loosened strands of the cable in the order and manner shown. When sufficient tucks have been made, the splice is pulled strongly and lightly beaten with a wooden mallet into a regular formation. The ends of the separate strands are then cut off flush with the cable and the cable in this neighbourhood is whipped with waxed thread.

449. When a splice is made round a thimble, care must be taken to see that the loop grips the thimble tightly. This is achieved mainly by pulling strongly on the first tucks ; a temporary whipping is sometimes of assistance.

Knots.

450. Fig. 104 gives a selection of useful knots. The purpose for which each is used is mentioned below :—

(i) *Thumb and figure of eight.*—To make a stop on a rope, to prevent the end from fraying, or to prevent the rope slipping through a block.

(ii) *Reef.*—To join two ropes of the same size together.

(iii) *Single sheet bend.*—To join two ropes of different sizes together.

(iv) *Bowline.*—To form a non-slipping loop at the end of a rope, or to secure the end of a rope to the hook on a block.

(v) *Bowline on a bight.*—To form a non-slipping loop in the middle of a rope, using a double of the rope.

(vi) *Hawser bend.*—To join two large cables together, of similar or different sizes.

(vii) *Clove hitch, timber hitch, and two half-hitches.*—To secure the end of a rope to a spar.

(viii) *Running bowline.*—To form a running noose at the end of a rope.

(ix) *Man harness hitch.*—To form a loop on a drag rope. The loop should be large enough to pass over a man's shoulder.

(x) *Catspaw.*—To secure the middle of a rope to the hook on a block.

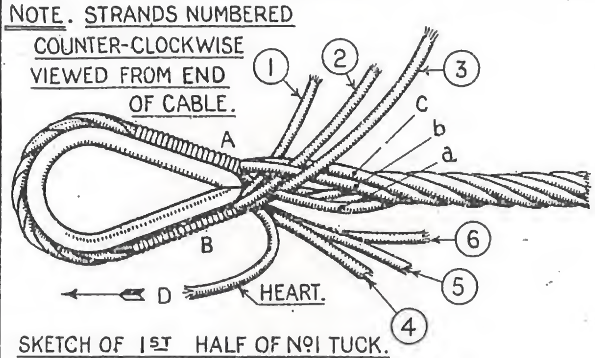
Cleaning of metal fittings.

451. Great care must be taken when cleaning metal fittings, as in many instances the material has been specially prepared to prevent corrosion (*see* Air Ministry Technical Order 301 of 1929). As already described in paras. 419 and 420, steels are protected by zinc and cadmium, and light alloys by the anodic or the chromate immersion treatments. Whichever treatment is adopted, the adherent film is exceedingly thin and can consequently easily be destroyed by mishandling. It is sometimes difficult to identify these treatments, especially that of the anodic process, since in many cases there is little difference in appearance before and after treatment.

452. When metal fittings require cleaning, all forms of scraping, such as rubbing with emery cloth or a wire brush, should be avoided. A paraffin bath and a soft brush or rag soaked in paraffin should be all that is required.

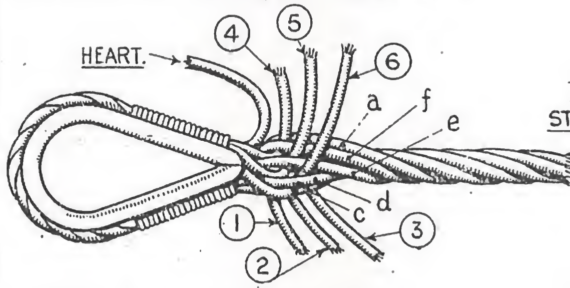
453. When removing paint or varnish, no abrasive methods should be employed, but the covering material

NOTE. STRANDS NUMBERED COUNTER-CLOCKWISE VIEWED FROM END OF CABLE.



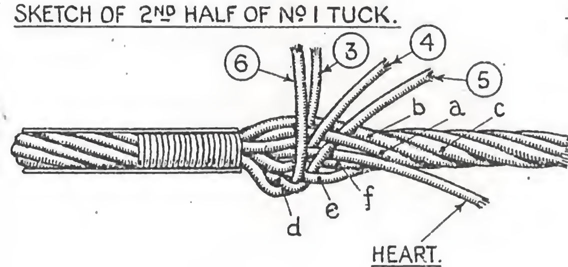
SKETCH OF 1ST HALF OF No. 1 TUCK.

CABLE SERVED AT A AND B WITH WAXED THREAD. CABLE BENT ROUND THIMBLE HEART TURNED BACK IN DIRECTION OF ARROW "D" No. 3 STRAND THREADED UNDER "a". No. 1 STRAND THREADED UNDER "b" AND "c". No. 2 STRAND THREADED UNDER "b".



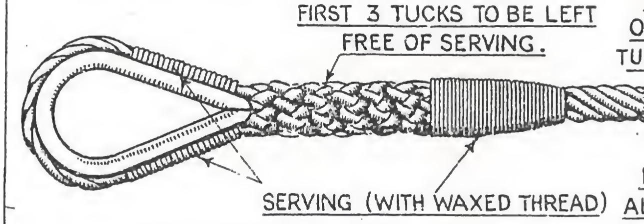
SKETCH OF 2ND HALF OF No. 1 TUCK.

No. 4 STRAND THREADED UNDER "f". No. 5 STRAND THREADED UNDER "e". No. 6 STRAND THREADED UNDER "d". ONE TUCK IS COMPLETED WHEN EACH STRAND HAS BEEN THREADED ONCE.



SKETCH OF COMMENCEMENT OF 2ND TUCK SHOWING HEART TUCKED IN.

IN THE 2ND, 3RD, 4TH AND THE HALF TUCKS, THE HEART IS LAID ALONG THE CABLE AND TAKEN UNDER A SUITABLE STRAND (IN ILLUSTRATION, No. 5 STRAND) THUS FORCING THE HEART INTO THE CENTRE OF THE SPLICE. IN THE 2ND, 3RD AND 4TH TUCKS THE STRANDS 1, 2, 3, 4, 5 AND 6 ARE TAKEN UNDER AND OVER ONE STRAND (a, b, c, d, e, f) e.g. No. 3 STRAND IS TAKEN OVER "b" UNDER "c" IN 2ND TUCK. OVER "d" UNDER "e" IN 3RD TUCK. OVER "f" UNDER "a" IN 4TH TUCK. HALF A TUCK IS MADE BY THREADING ALTERNATE STRANDS ONCE. A COMPLETE SPLICE CONSISTS OF 4½ TUCKS. ON COMPLETION OF SPLICING LOOSE ENDS CUT OFF FLUSH AND SERVED.



SKETCH SHOWING COMPLETE SPLICE.

FIG. 103. METHOD OF LOOP SPLICING FLEXIBLE STEEL CABLES.

P.3882.

To face page 163.

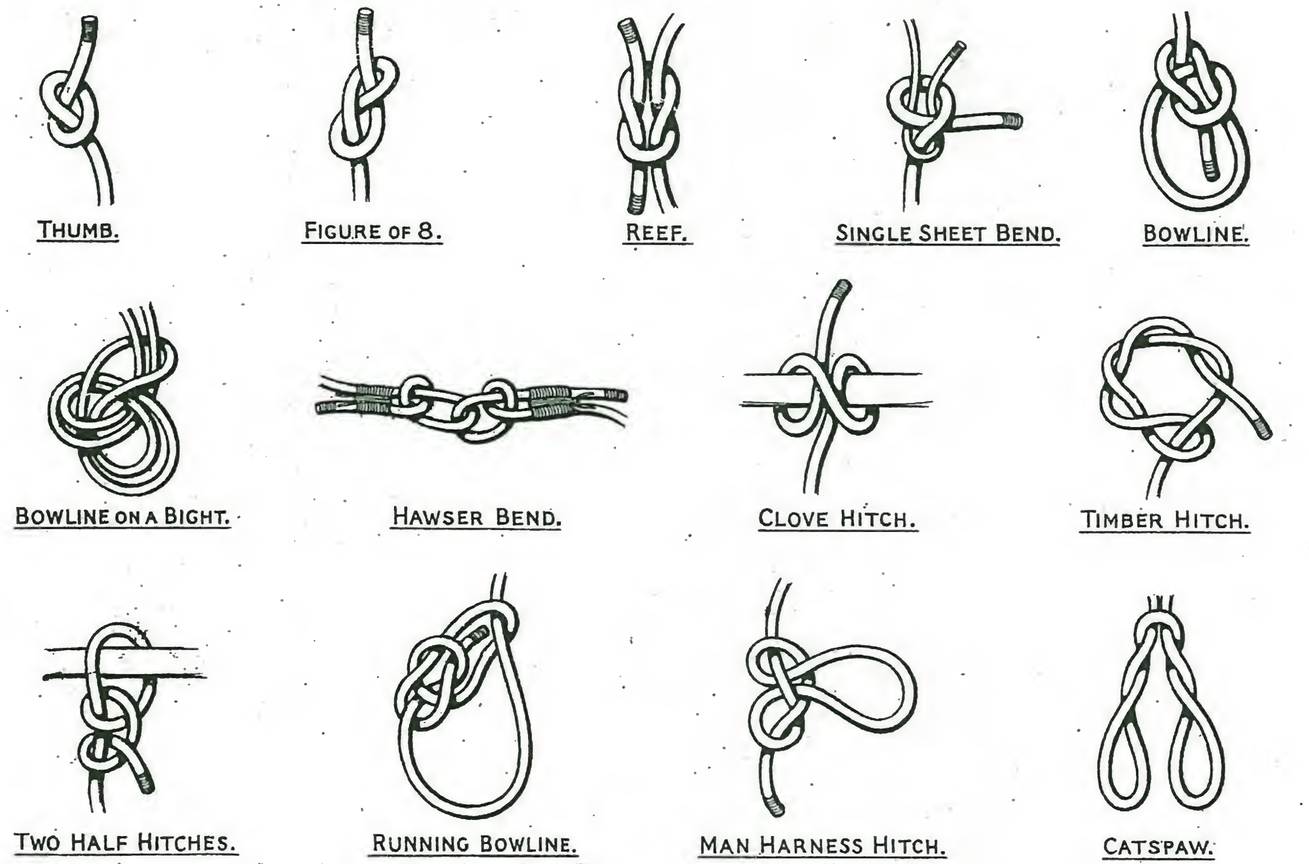


FIG. 104. KNOTS.

should be softened with the varnish remover (N.S.40) Stores Ref. 11/40, and rubbed with a rag soaked in this solvent. Stove-enamelled fittings are not usually treated with zinc or cadmium, and therefore the normal methods of removing stove enamel may be employed. After removal of the defective paint or varnish, all fittings should be re-coated with the appropriate protective covering, with the exception of the side and bottom fuselage cowlings and the metal parts of undercarriages and radiators. These parts, if desired, need not be re-painted, but may be kept clean and bright by using metal polish or an oil-soaked rag.

Inspection doors in planes.

454. Metal inspection doors in main planes should be very closely watched, especially if situated in the slipstream region, as fastenings which would normally be regarded as quite secure may possibly become detached through vibration and the effects of the slipstream. Should this occur the inspection door may fly back with considerable force, involving a possible injury to the pilot or the fouling of control cables.

Rip-off patches on planes.

455. Inspection doors are usually provided only at those positions where frequent inspection or lubrication of the internal fittings is required. Where only occasional inspection or adjustment is required for internal fittings, such as bracing wires, a special form of patch is used which is capable of being torn off and renewed as necessity demands. There are several types and shapes of patches, but in all cases a light frame is secured to the fabric covering of the wing and the fabric enclosed by the frame cut away, thus providing a hole with a non-frayable edge. A covering patch of frayed fabric large enough to envelop the frame is then doped on to the plane over the hole as indicated at C, fig. 105. When it is necessary to place a rip-off patch on a plane, the frames should preferably be of the circular type with an internal diameter of $4\frac{1}{2}$ in. to 5 in., but other shapes can be adopted to suit special conditions. Fig. 105 shows two types of frames, the type employing the aluminium frame being perhaps the better one.

456. Aluminium frames should not be made from less than 24 S.W.G. material, and celluloid frames should have the edges slightly chamfered, and should not be thinner than 1·5 mm. As indicated at A, fig. 105, the aluminium frames are first mounted on a sheet of frayed fabric, and attached thereto by means of the fabric tongues formed by radial cuts from the centre of the patch. The tongues are folded outwards

over the frame and doped down. The frayed fabric and the frame are then doped on to the plane. Celluloid frames are doped directly to the plane covering, as indicated at B, fig. 105, the dope being applied to both the frame and the fabric. Care must be taken to ensure that all air is excluded from between the doped surfaces. After the frames have been fixed in position, the fabric within the frame should be cut away with a sharp knife.

457. To remove a patch, knife-cuts are made across the opening as shown at C, fig. 105, and the patch ripped off in sections from the centre outwards.

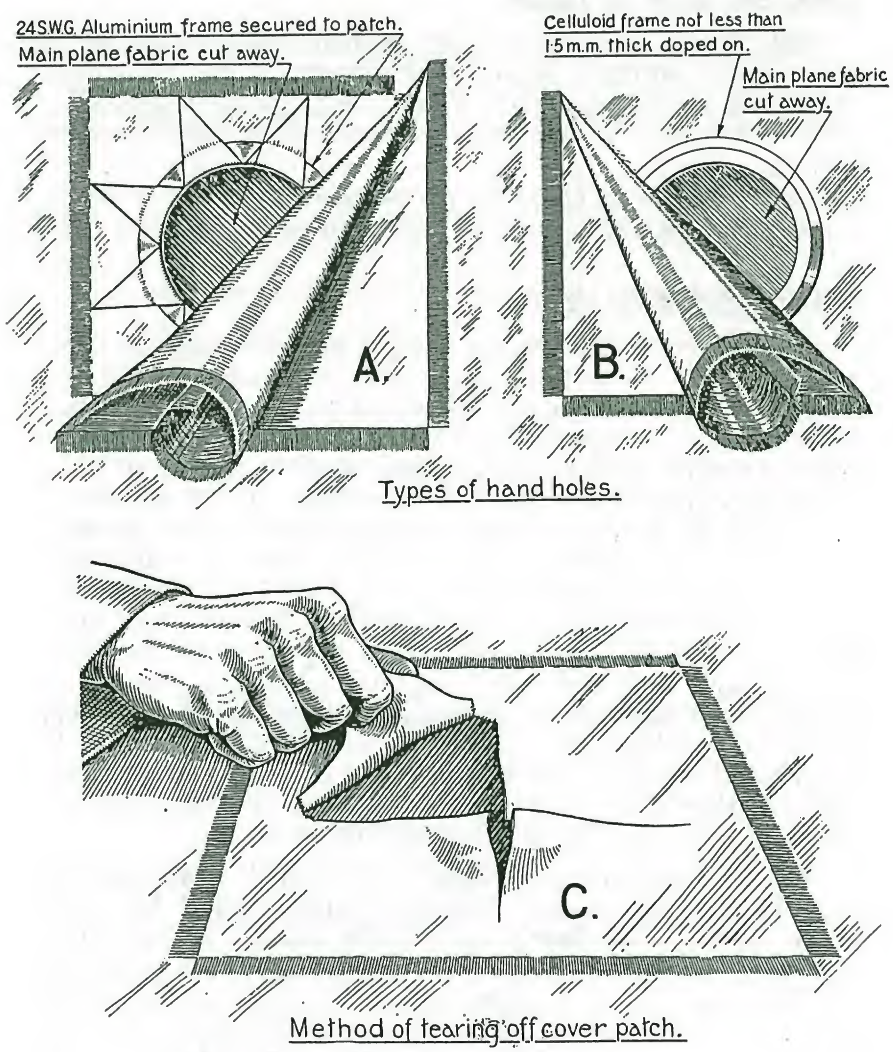


FIG. 105.—Rip-off patches on planes.

Detachable fairings.

458. When the flush-fitting type of cowling clip is used, special precautions must be taken to ensure that the clips are actually securing the fairing to the structure, as the fairing is in a dangerous condition if one of the clips does not catch as it should. It is usual to arrange for the screwdriver slots or other operating mechanism to be all in one direction so that the position of the catch can be ascertained at a glance. If this has not been arranged, suitable marks should be made on the clip, the marks being all in one direction when they are attached.

Renewing control cables.

459. Special arrangements are usually made for the renewal of all cables, but where this is not so, it is a good plan to tie a cord to the end of the cable to be withdrawn, and pull the cord over the pulleys and through the fairleads, etc., as the old cable is removed. Before the old cable is taken away, tie the two ends of the cord to any convenient fitting. The cord enables the new wire to be drawn into position without the difficulty of threading it through fairleads or over pulleys.

Lubrication.

460. The lubrication system of an aircraft should receive careful study by the rigger and the special instructions which are issued with the maintenance notes must be closely followed, but some general guidance on the matter is given below.

461. As a rule, manufacturers provide adequate means for lubrication, usually by the provision wherever necessary, of grease gun nipples. Every care must be taken to ensure that the lubricant used is actually reaching the surfaces in contact, even if this involves a small amount of dismantling and re-assembling. Normally, all flying controls are lubricated with anti-freeezing oil, Stores Ref. 34A/46 and 43, and all other parts with heavy steam cylinder oil, Stores Ref. 34A/47 and 18. Grease is not supplied to R.A.F. units as a lubricant for any aircraft part, because it tends to solidify when subject to very low temperatures such as those encountered at high altitudes. A mixture of grease and steam cylinder oil is, however, a suitable lubricant for the hubs of aircraft landing wheels. "Little and often" is a good general maxim in all questions of lubrication.

Care of shock-absorbers.

462. The shock-absorber legs on the undercarriage of any aeroplane should be of equal length under any given load, and, where this is not the case, an examination should be made to

ascertain the cause of the unequal extension. Gauge marks are normally provided to indicate the approximate safe minimum length.

463. As described in paras. 201 to 204, modern shock-absorbers consist of rubber in compression, oil or air dashpot oleos or a combination of both. Steel springs are also used at times, but they are not a common type of fitting.

464. Rubber shock-absorbers should be kept scrupulously free from oil or grease, because in the first place rubber rapidly deteriorates with any contact with oil, and, secondly, the correct shock-absorption is not obtained if the rubber is so lubricated. The only form of lubricants which can be successfully used in conjunction with rubber are powdered french chalk or graphite. All shock-absorber rubbers should be totally enclosed so as to exclude the light, especially in tropical countries, and if a covering has not been provided it is advisable to fit some form of stocking for this purpose.

465. Compression rubbers should not be screwed up to such an extent as to give excessive initial compression, as this increases the shock loads on the aircraft and also because the rubber will in time have a permanent set if placed under a steady heavy load (see Air Ministry Technical Order 49 of 1929). For this reason, aeroplanes with rubber shock-absorbers which are being stored for any length of time should be jacked up to take the weight off the rubbers.

466. Oil or air oleos should be frequently examined and re-filled with oil or air, as directed in the maintenance notes of the type.

Inflation of tyres.

467. Aircraft tyres should be inflated to a pressure of 60 lb. to 75 lb. a sq. in., depending on the size. The inflation pressure, which is sometimes marked on the outside of the cover, is tested by using a standard tyre-pressure gauge.

468. In tropical climates, care must be taken not to inflate to an excessive pressure, as the sun temperature will expand the air in the tyres and may burst the cover.

469. The standard two-stroke gas starter for aero engines can be very effectively employed for inflating tyres of aircraft. A gas starter, mounted on a four-wheel truck for aerodrome use, has been used, and the only change found necessary is the fitting of an adaptor nozzle for the tyre valve, and a cock to turn off the petrol supply to the auxiliary carburettor. The adaptor is fitted directly to the end of the mixture supply pipe used for starting, and no modification to the latter is involved. The adaptor should be provided with a calibrated release valve to prevent over-inflation of tyres.

Aileron stop, temporary.

470. When erecting the planes or adjusting aileron controls, some means must be provided to hold the ailerons in line with the main planes. The device illustrated in fig. 106 is designed to hold the ailerons normal while the cables are being adjusted,

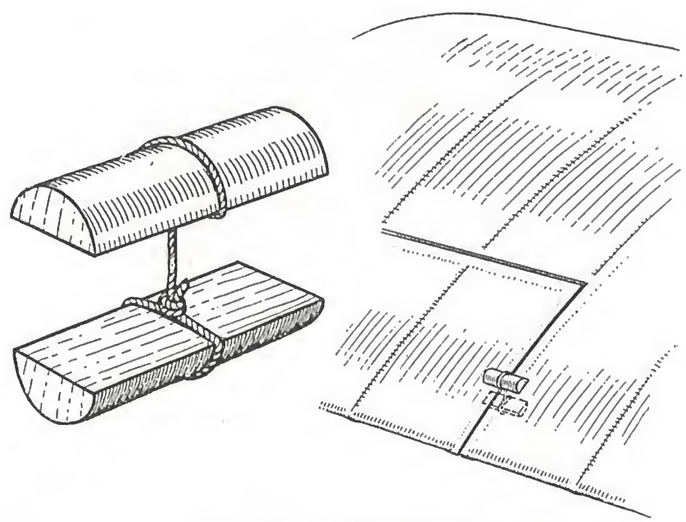


FIG. 106.—Aileron stop.

and is used by pushing the connecting cord in the crevice between aileron and plane, so that the two pieces of wood hold aileron and main plane in the same straight line. Similar devices for this purpose can be made up by the rigger as required.

APPENDIX I.

CHECKING CENTRE OF GRAVITY.

Procedure. (i) Place the aircraft on platform scales, one scale under the wheels and the other under the tail skid, as shown at A, fig. 108. Adjust the jack under the tail until the angle of incidence of the bottom plane is zero. Check on port and starboard planes. Take scale readings, giving P for wheels and Q for skid after deducting the "zero" reading due to the weight of trestles, jacks, etc. The total weight of the aeroplane will be given by $P + Q = W$. Drop a plumbline from the point of support of the skid and measure the horizontal distance (l) between the axle centre line and the skid support. Measure the height (a) of the skid support above the axle centre line. Drop a plumbline from the leading edge of the bottom plane at the root and measure the distance D between the axle centre line and the leading edge. Measure the height H of the chord above the axle centre line.

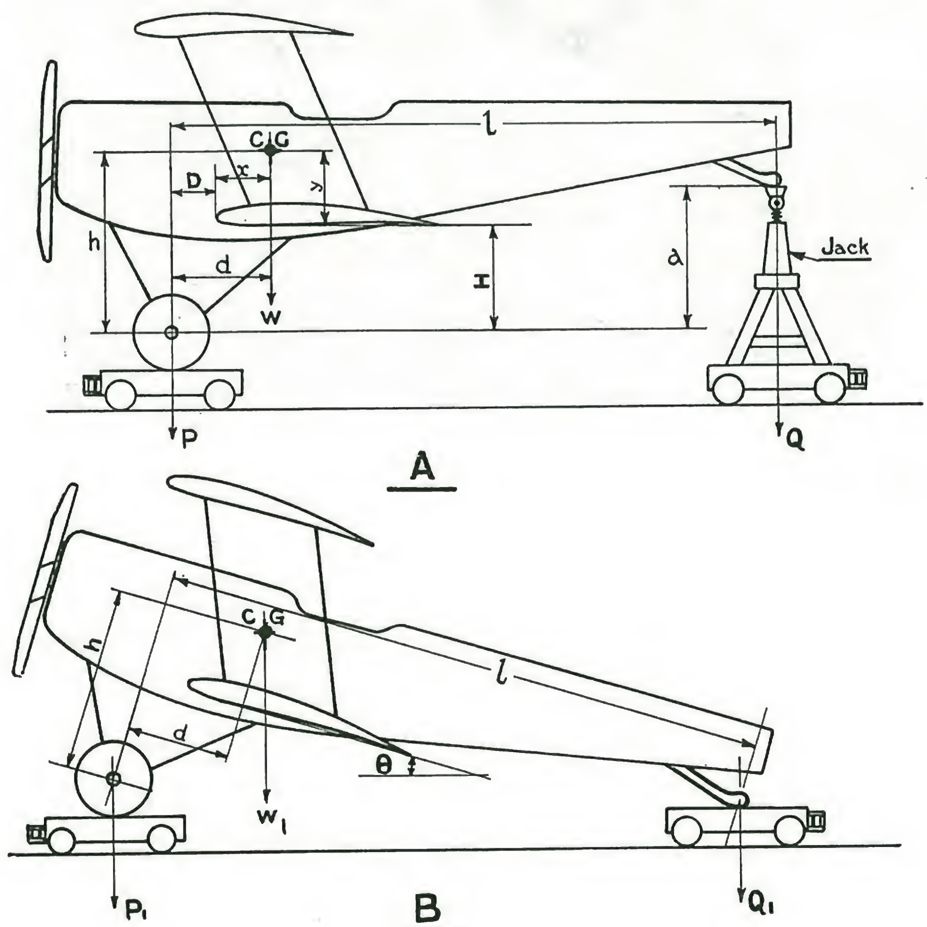


FIG. 108.—Checking C.G. of an aeroplane.

(ii) Lower the tail skid to the level of the point of support of the wheels as shown at B, fig. 108. Measure the angle of inclination to the horizontal of the bottom plane chord θ. Check on port and starboard planes. Take new weight readings, giving P_1 and Q_1 after deducting zero readings. Check the new total weight $W_1 = P_1 + Q_1$ and if different from W take the mean weight $= \frac{W + W_1}{2}$.

(iii) If d is the horizontal distance of the centre of gravity behind a straight line through the wheel centres, at right angles to the chord, then :—

$$d = \frac{lQ}{W}.$$

Also, if h is the perpendicular distance of the centre of gravity above the wheel centres, at right angles to the chord, then :—

$$h = \frac{aQ_1}{W} + \text{Cot}\,\frac{Q_1 - Q}{W}.$$

The position of the centre of gravity is quoted by its distance x along the chord line from the leading edge, and its height y at right angles to this line at point x. As will be deduced from fig. 108, when the wheel centre line is forward of the leading edge $x = d + D$ and when behind the leading edge $x = d - D$. Also, if the C.G. is above the plane of reference, normally the bottom plane of a biplane, $y = h - H$, but if the C.G. is below (as in a monoplane) then $y = H - h$.

(iv) The method employed by the Aeronautical Inspection Directorate of determining the centre of gravity of an aircraft is detailed in the Inspection Instruction No. A4. Either the method set out above or that given in the leaflet A4 can be used, and, if care is exercised and reliable weighing machines are employed, accurate results can be obtained. The method described in the A.I.D. inspection leaflet is more suited for new types of aircraft, or those in which modifications have been made affecting the weight distribution.

APPENDIX II.

THREAD AND TAPPING DRILL SIZES.

British Association Standard Threads.

B.A. No.	Diameter.	Pitch of thread.	Dia. at root of thread.	Size of Tapping drill.
0	0·2362	0·0394	0·1890	No. 12
1	0·2087	0·0354	0·1662	
2	0·1850	0·0319	0·1467	No. 26
3	0·1614	0·0287	0·1269	
4	0·1417	0·0260	0·1105	No. 34
5	0·1260	0·0232	0·0981	
6	0·1102	0·0209	0·0852	No. 44
7	0·0984	0·0189	0·0757	
8	0·0866	0·0169	0·0663	No. 51
9	0·0748	0·0154	0·0564	
10	0·0669	0·0138	0·0504	No. 54

Whitworth Standard Threads.

Dia. in inches.	No. of threads per in.	Dia. at root of threads.	Tapping drill, size : in.	Dia. in inches.	No. of threads per in.	Dia. at root.	Tapping drill, size: in.
1/4	20	0·1860	3/16	7/16	14	0·3460	23/64
5/16	18	0·2414	1/4	1/2	12	0·3933	13/32
3/8	16	0·2950	19/64	5/8	11	0·5086	33/64

British Standard Fine Threads.

Dia. in inches.	No. of threads per in.	Dia. at root of threads.	Tapping drill, size : in.	Dia. in inches.	No. of threads per in.	Dia. at root of threads.	Tapping drill, size: in.
7/32	28	0·1731	17	9/16	16	0·4825	31/64
1/4	26	0·2007	7	5/8	14	0·5335	35/64
9/32	26	0·2320	A or 15/64	11/16	14	0·5960	39/64
5/16	22	0·2543	G or 17/64	3/4	12	0·6433	21/32
3/8	20	0·3110	0 or 5/16	13/16	12	0·7058	23/32
7/16	18	0·3664	U or 23/64	7/8	11	0·7586	49/64
1/2	16	0·4200	27/64	1	10	0·8719	7/8

Wire Gauge Drill Sizes.

No. Drill.	Size in inches.	No. Drill.	Size in inches.	No. Drill.	Size in inches.	No. Drill.	Size in inches.
1	0·2280	16	0·1770	31	0·1200	46	0·0810
2	0·2210	17	0·1730	32	0·1160	47	0·0785
3	0·2130	18	0·1695	33	0·1130	48	0·0760
4	0·2090	19	0·1660	34	0·1110	49	0·0730
5	0·2055	20	0·1610	35	0·1100	50	0·0700
6	0·2040	21	0·1590	36	0·1065	51	0·0670
7	0·2010	22	0·1570	37	0·1040	52	0·0635
8	0·1990	23	0·1540	38	0·1015	53	0·0595
9	0·1960	24	0·1520	39	0·0995	54	0·0550
10	0·1935	25	0·1495	40	0·0980	55	0·0520
11	0·1910	26	0·1470	41	0·0960	56	0·0465
12	0·1890	27	0·1440	42	0·0935	57	0·0430
13	0·1850	28	0·1405	43	0·0890	58	0·0420
14	0·1820	29	0·1360	44	0·0860	59	0·0410
15	0·1800	30	0·1285	45	0·0820	60	0·0400

LETTER DRILL SIZES.

Letter.	Dia. in inches.	Letter.	Dia. in inches.	Letter.	Dia. in inches.	Letter.	Dia. in inches.
Z	0·413	T	0·358	N	0·302	H	0·266
Y	0·404	S	0·348	M	0·295	G	0·261
X	0·397	R	0·339	L	0·290	F	0·251
W	0·386	Q	0·332	K	0·281	E	0·250
V	0·377	P	0·323	J	0·277	D	0·246
U	0·368	O	0·316	I	0·272	C	0·242
						B	0·238
						A	0·234

APPENDIX III.*

Possible extension of tolerances on blade angles for wooden airscrews.

Although the blade angles of certain wooden airscrews may be found to be slightly outside the tolerances allowed for new construction, it is possible that they may still be serviceable from considerations of rotational speeds. Whilst it is difficult to decide in the absence of extensive tests to what extent these tolerances may be increased for wooden airscrews in use, the following are suggested :—

Class A $\pm$ 1° on the angles given on the drawing over the outer two-thirds of the blade length.

Airscrew Drg. No.	*Aircraft.*	*Engine.*
S.88C/232	Rangoon	Jupiter XIF.
19044A	Flycatcher	Jaguar IV.
Z.129	Hinaidi	Jupiter VIII.
Watts 730	Horsley	Condor.
29967	Ripon	Lion XIA.
Watts 861 & Watts 869	Hart	F.XIB.
3895	Sidestrand	Jupiter VIII & VIIIF.
24738	Wapiti	Jupiter VI.

Class B $\pm \frac{3}{4}$° on the angles given on the drawing over the outer two-thirds of the blade length.

Airscrew Drg. No.	*Aircraft.*	*Engine.*
Y.573	Avro 504N	Lynx.
Y.689	Tutor	Mongoose.
PD.8019	Blackburn or Dart	Lion.
P.3274	Bulldog	Jupiter VII.
P.3317A	Bulldog	Jupiter VIIF.
T.28925	D.H.9A	Liberty.
T.29334	Gamecock	Jupiter VI.
F.2567	Grebe	Jaguar IV.
DH.5180/5	Moth	Gipsy.
8820	Sidestrand	Jupiter VI.
SP.3420A	Siskin	Jaguar.
SP.4291A	Siskin	Supercharged Jaguar.
Watts 908	Tomtit	Mongoose.
10955	Vernon	Lion.
16273	Vimy	Jupiter IV.
3830	Southampton	Lion.

Difference of angles on the opposite blades must remain as for new construction, i.e., 1° over the outer two-thirds of the blade length.

* SPECIAL NOTE.—This Appendix applies only to wooden airscrews which have been in R.A.F. Depôts or in use for some time.

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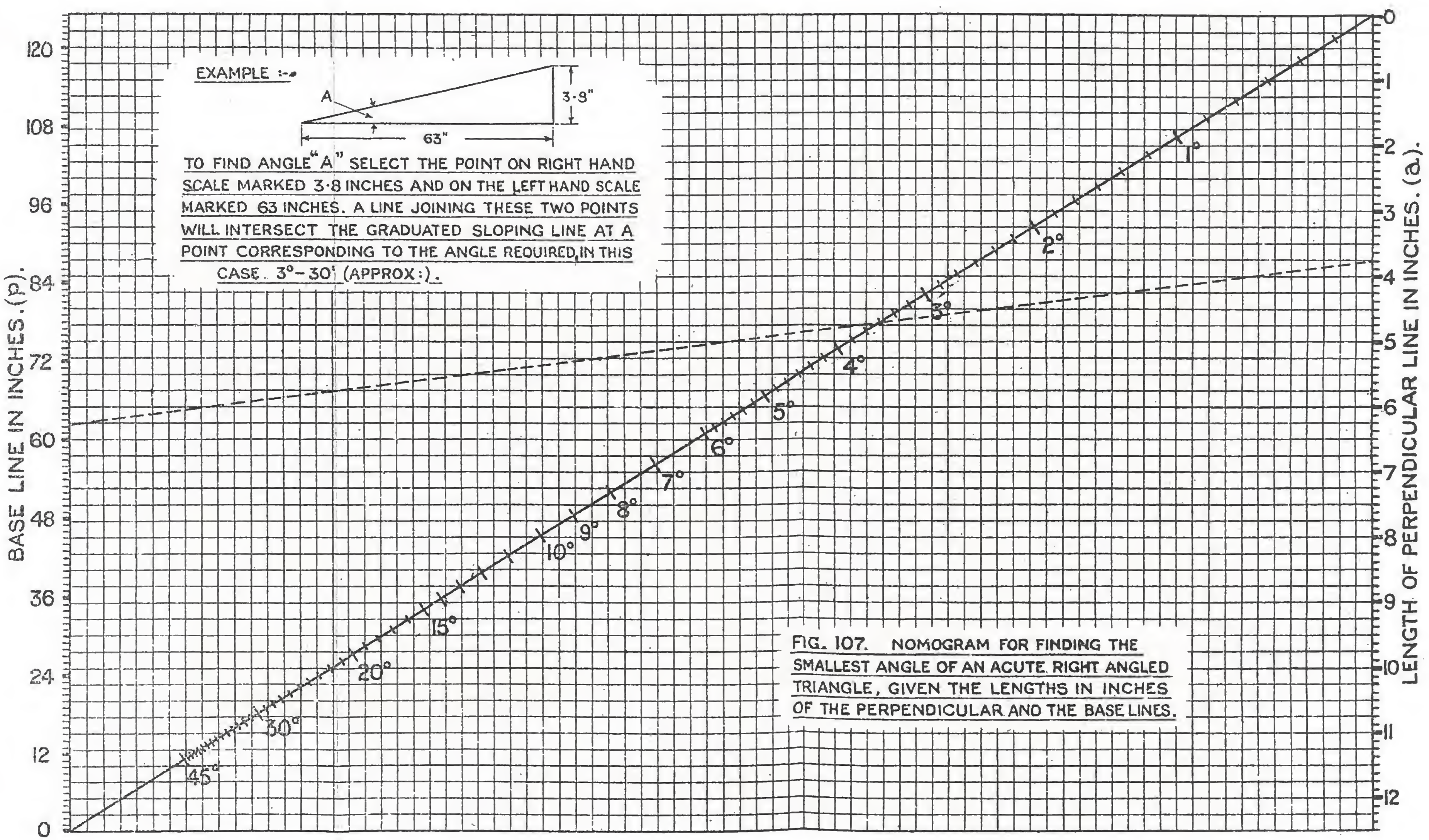

FIG. 107. NOMOGRAM FOR FINDING THE SMALLEST ANGLE OF AN ACUTE RIGHT ANGLED TRIANGLE, GIVEN THE LENGTHS IN INCHES OF THE PERPENDICULAR AND THE BASE LINES.

P.3882,

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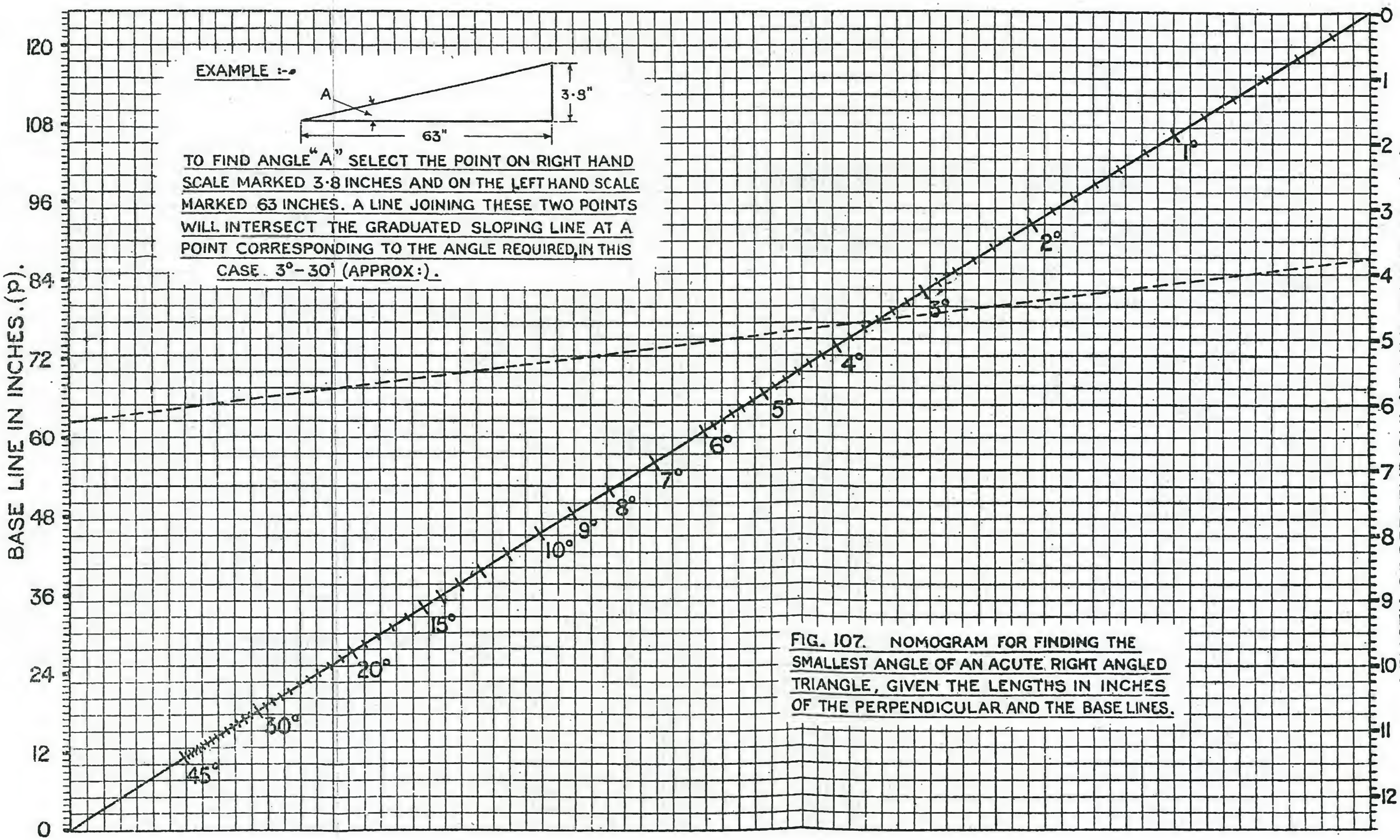

FIG. 107. NOMOGRAM FOR FINDING THE SMALLEST ANGLE OF AN ACUTE RIGHT ANGLED TRIANGLE, GIVEN THE LENGTHS IN INCHES OF THE PERPENDICULAR AND THE BASE LINES.

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